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FUTURE TRENDS FORUM

Neurotechnology for human wellness

Improving people's quality of life, the tall order for neuroscience, neurotechnology and synthetic biology

Moving an exoskeleton with the mind, ending Parkinson's tremors, preventing and curing mental illnesses such as Alzheimer's, regenerating organs with bioelectricity or improving human abilities and capacities are some of the challenges facing society discussed by the experts gathered at the Future Trends Forum, including the opportunities and the ethical and legal challenges of this exciting field.

Contenido

Introduction

Introduction

The Future Trends Forum think tank of the Bankinter Innovation Foundation held its latest edition: "**From repairing to improving human capabilities**", with a focus on **the future of neuroscience, neurotechnology and synthetic biology**. It brought together 38 international experts to discuss the opportunities and risks of these emerging technologies.

Throughout the forum, experts highlighted the **potential that these technologies offer to revolutionize our understanding of the human brain and to develop new treatments for a wide range of neurological disorders**. They also discussed the potential of these technologies to improve human abilities such as memory, intelligence, and creativity.

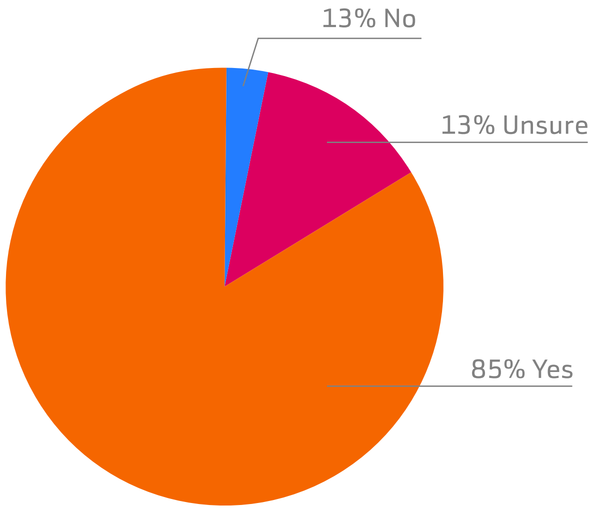
They also warned of the associated risks, particularly the possibility of misuse, such as manipulating or controlling people's thinking and behavior. Synthetic biology could be used to create new pathogens. They also expressed concern about the ethical implications of using these technologies to improve human capabilities.

And 85% of experts believe that the benefits of human enhancement technologies far outweigh the associated risks and threats (graphic 1).

This report highlights the need to **develop international guidelines and regulations to ensure that these technologies are used safely and ethically, without slowing down their development**. It also stressed the importance of encouraging research about their potential benefits and risks, so that we can make well-informed decisions about their future use.

The meeting of the Future Trends Forum think tank of the Bankinter Innovation Foundation on neurotechnology and human capabilities is included in this report, which delves into the challenges and opportunities of these innovative technologies, with the potential to improve the future of humanity.

Graphic 1: In your view do the potential benefits of human technological enhancement outweigh the threats?



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Neuroscience and Neurotechnology

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Neuroscience and Neurotechnology

Overview

Neuroscience and neurotechnology are rapidly developing fields that have made significant advances in recent years. These advances have enabled scientists to **better understand how the brain works** and have led to the development of new technologies that can be used to **treat disease, improve cognitive performance**, and enhance **quality of life**.

One of the most important advances in neuroscience has been the development of **new brain imaging techniques**. These techniques allow scientists to observe the brain at work, which has led to a better understanding of how information is processed, and decisions are made. For example, *functional magnetic resonance imaging* (fMRI) enables scientists to see how brain activity changes in response to different stimuli. This has been used to study a wide range of diseases and disorders, from depression to Alzheimer's disease.

Another important advance in neuroscience has been the development of **new neurostimulation technologies**. These technologies use electrical or magnetic pulses to stimulate the brain, which can be used to treat diseases such as Parkinson's disease, epilepsy and depression. For example, *transcranial direct current stimulation* (tDCS) uses a mild electrical current to stimulate the brain, which has been shown to be effective in improving cognitive performance and reducing symptoms of depression.

Despite the advances made in neuroscience and neurotechnology, there are still some major challenges. One of the most important challenges is understanding the complexity of the brain. The brain is an incredibly complex organ, with billions of interconnected neurons. This makes it difficult to study and understand its inner workings.

For Antonio Damasio, a globally renowned neuroscientist and a trustee of the Bankinter Foundation of Innovation, **neuroscience and neurotechnology are two sides of the same coin**: neuroscience lays the foundations for understanding the brain's emotional circuits, while neurotechnology provides the tools to study these circuits in vivo. Together, these two fields are opening up new possibilities for understanding and treating neurological disorders, and for developing new technologies that can improve human cognition and behavior. Prof. Damasio synthesizes the goals of neuroscience and neurotechnology: **to achieve improved healthy longevity and the well-being of humankind** and illustrates the state of the art of neurotechnology with the world's first case of a paraplegic person who can walk with the help of a thought-controlled implant.

From the point of view of pure science, Professor Damasio presents his findings on human consciousness and the necessary distinction between mind and conscious mind. This is a fundamental step in understanding, interpreting and, if necessary, curing neurological disorders and diseases.

Prof. Damasio says that the conscious mind arises from our **homeostatic feelings**. Homeostatic feelings help us maintain a sense of balance and well-being. They include the feelings of hunger, thirst, fatigue, and pain. These feelings are triggered by changes in our internal environment, such as changes in blood sugar levels, body temperature or the amount of oxygen in the blood. Homeostatic feelings are important because they help us maintain a healthy state. For example, hunger tells us to eat when our blood sugar levels are low, thirst tells us to drink when we are dehydrated, and fatigue tells us to rest when we are tired. Pain tells us to avoid harmful stimuli.

Homeostatic feelings are regulated by the hypothalamus, which receives signals from our internal organs and the environment and uses them to regulate our homeostatic feelings.

Thus, as the professor says, "**consciousness does not arise from the most sophisticated part of the nervous system—the prefrontal cortex—, but from the humblest—the hypothalamus**".

> **"The goals of human enhancement technologies: to achieve improved healthy longevity and the well-being of humankind"**
>
> **Antonio Damasio**

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The philosophy of neuroscience

Along these lines, during the forum there was a conversation between Antonio Damasio and Asier Arias, Professor in the Department of Logic and Theoretical Philosophy at the Complutense University of Madrid (UCM) in which a particularly intriguing topic was addressed: **consciousness from a philosophical point of view.** This discussion did not focus on moral consciousness or our perception of who we are, but on **consciousness related to felt experience**.

Thus, Asier Arias stressed the importance of correctly defining consciousness, while Prof. Damasio pointed out that the term "consciousness" is often confused due to linguistic and cultural differences, since in many Romance languages the word for consciousness also refers to ethics. Furthermore, in popular discourse, conscience is often used to denote attention or awareness. Damasio proposed that we use the term "consciousness" when referring to experience. **Consciousness**, in this context, is **about having an experience of oneself, a combination of mind and body, which generates subjectivity**.

The discussion also delved into the difference between exteroception (perception of the external world) and interoception or proprioception (perception of the internal world). Damasio argues that, while we perceive the external world without directly interacting with it, we constantly interact with our inner world. **This constant interaction between the body and the nervous system is fundamental to consciousness**.

Asier Arias concluded the conversation by highlighting the importance of interoception as the grounds for consciousness. The discussion between these two experts sheds light on the complexity and depth of consciousness, a topic that remains a mystery in the field of neuroscience.

Asier Arias

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> **Neurotechnology is the set of methods, tools or devices that record or modulate the activity of the nervous system. These devices can be electrical, optical, magnetic, acoustic, nanotechnological or chemical, and are now combined with artificial intelligence and deep neural networks.**
>
> **Rafael Yuste**
>
> Director of the Center for Neurotechnology and Professor of Biology at Columbia University and President of the NeuroRights Foundation.
>
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Neurotechnological applications

We already have **neurotechnology that allows us to measure and characterize brain activity related to behaviors, cognitive abilities, and emotions**. In addition, technology also enables us to **modify brain activity** and, therefore, behaviors, cognitive abilities, and emotions.

On the other hand, we are gaining fundamental knowledge about the functioning of the human brain and are beginning to be able to a**ddress brain-related disabilities** with **precise and personalized interventions**. But the same technologies can disrupt individual autonomy and alter human choice, behavior and perception, requiring **careful ethical and human rights review before any intervention is made**.

Modificación de la actividad cerebral

According to Álvaro Pascual-Leone, Professor of Neurology at Harvard Medical School, the applications of neurotechnology are still at a very early stage: we are just at the "tip of the iceberg" of what is to come. With this in mind, he argues that **the focus should be on the prevention and treatment of diseases or disabilities**, before addressing improvements in human capabilities of healthy people.

As regards the latest neurotechnology applications, the professor explains that neurons themselves are not considered the functional units of the brain, but rather the spatiotemporal relationships between groups of neurons. There are tools to characterize these relationships between groups of neurons in both the temporal and spatial dimensions. In much the same way, a functional map of brain activity can be created for each behavior, thought and feeling. That is, **each behavior/thought/feeling represents a specific neural network characterized by a specific spatial-temporal signature**.

So, to understand neurological diseases or brain malfunctions, one can compare the functional signatures in healthy people with the functional signatures of patients with conditions. One step further, one can try to **change the functional signature of a patient with a given problem to correct symptoms and disabilities**.

Speaking of the innovations in the **modification of brain activity**, or **neuromodulation** with brain-computer interfaces, Professor Pascual-Leone mentions the significant improvements in episodic memory in Alzheimer's patients achieved with the solution proposed by the Spanish startup Neuroelectrics, whose CEO, Ana Maiques, is also part of the group of experts gathered at the Future Trends Forum. Alzheimer's patients are given non-invasive brain stimulation (NIBS) in the form of transcranial alternating current stimulation (tACS), reliably and safely, in the comfort of their homes. Using cloud-based monitoring and control tools, patients can be individually tracked and any necessary changes to the program can be made. After 14 weeks of daily treatment, Alzheimer's patients are able to recover their memory to the levels they had two and a half years before treatment.

Álvaro Pascual-Leone

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It should be noted that these data are sourced from a preliminary study, to be followed by a large randomized controlled trial, prior to commercialization.

Currently, the therapeutic prospects of this solution are being evaluated for disorders such as: depression, panic, anxiety, obsessive compulsive disorder, schizophrenia, dementia, migraine and also for neurological pathologies in pediatric age such as: autism, pervasive developmental disorders, attention deficit disorder, mental retardation, learning disabilities and cerebral motor disease.

The professor also explains how **neuromodulation can speed up the acquisition of skills**, for example, learning to play the piano. With the application of neuromodulation two hours a day for five days in a row, while practicing piano, it is observed that a certain area of the motor cortex is activated much more powerfully and extensively than at the beginning. Based on these findings, studies are being conducted on the potential advantages of applying neuromodulation before and during the acquisition of new skills, both motor and intellectual.

Neuroplasticity, artificial intelligence and neurotechnology

Combining brain plasticity—the capacity of the nervous system to modify its state, by creating neuronal structures and connections based on the environment—, with the latest advances in artificial intelligence and neurotechnology, a **new generation of brain-computer connection systems** is being created, where the key is the **generation of feedback loops between the brain and the automatic learning systems**. The ultimate goal of this type of system is to **develop neuroprostheses that induce neuroplasticity that can reprogram the brain** after trauma, to unlearn neuropsychiatric disorders and, one step further, to improve human capabilities. This is explained by José Carmena, Professor of Electrical Engineering and Neuroscience at the University of California-Berkeley, Co-Director of the Center for Neural Engineering and Prosthetics at the same university and founder and Co-Chief Executive Officer of iota Biosciences.

In this type of solution, invasive neurotechnology is used, i.e., the sensors and actuators are implanted in the brain, which is what is known as **neuroprosthesis**. There are two particular challenges to be solved in this field:

José Carmena

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The available technology is still bulky and requires actual wiring. Therefore, it is necessary to **advance in the miniaturization of the technology and in wireless communication protocols**. In addition, neuroprostheses should be as minimally invasive as possible.

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Progress must also be made in **improving the performance and accuracy of brain control with external devices** (such as a robotic arm).

There have been significant neuroscientific advances in the **voluntary control of neuronal activity to carry out a given task**. Studies with primates suggest that it is possible to train a random group of neurons in the neocortex to learn new skills.

By combining advances in both fields (neuroprosthetics and voluntary control of neuronal activity), Prof. Carmena believes it is possible to create **new closed-loop systems that could correct and treat disabilities** and also open up a **new set of skills in people** that are difficult to imagine today, such as interacting in a more 3-dimensional environment. This is what he calls **abstract skills or abilities**. Beyond moving and controlling our body, we might be able to interact with external devices that perform tasks beyond human reach.

In this closed-loop system where the brain, the neuroprosthesis and the signal decoder act to feed the artificial intelligence system, which in turn feeds back to the brain through the neuroprosthesis, it is essential to update the decoder and the artificial intelligence system during operation to accelerate learning and increase and maintain performance. When to update which parameters and in what way becomes particularly important, as this is a cutting-edge field of research.

This type of system can be applied to **treat depression**: mood can be decoded from intracranial neuronal activity, and when depression is detected, brain stimulation alleviates the symptoms. The ultimate goal of this application is for the patient to be able to **unlearn inappropriate behaviors**.

The future points toward closed-loop deep brain stimulation therapies with much less invasive solutions, says Prof. Carmena.

Specific neurons in the human brain

Concept cells, also known as "Jennifer Aniston neurons"—because of a study in which a specific neuron responded to the concept of actress Jennifer Aniston—are a specific type of neuron found in the human brain. These cells are activated in response to specific concepts, meaning that each of these neurons is activated when a person thinks of a specific concept, such as a person, place, or object.

Rodrigo Quian-Quiroga

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The discovery of concept cells by Rodrigo Quian-Quiroga, ICREA Research Professor at the Hospital del Mar Medical Research Institute, has revolutionized our understanding of how the human brain processes information. Prior to this discovery, it was thought that the brain processed information in a more distributed manner, with many neurons contributing to the representation of a single concept. However, the discovery of concept cells suggests that the brain can represent concepts in a much more specific and localized manner. These concept cells are found in the hippocampus, a region of the brain that is crucial for memory formation. When a person experiences something, such as watching a movie or meeting a new person, the concept cells in his or her brain are activated in response to the concepts associated with that experience. These cells then help store that experience in memory by associating it with the relevant concepts.

In addition to their role in memory formation, concept cells may also play a role in human intelligence. Prof. **Quian-Quiroga suggests that the brain's ability to represent concepts in such a specific and localized way could be a key mechanism underlying human intelligence**. This ability to represent and manipulate concepts so precisely may be what allows us to think abstractly, solve complex problems, and learn from our experiences.

When asked whether it would be appropriate to use neurotechnology to increase human capabilities, and in particular, memory, Prof. Quian-Quiroga believes that the **ability of human beings to selectively forget is what makes them unique in terms of intelligence and consciousness**. So, increasing human memory could be counterproductive and reduce our ability to solve difficult problems.

Our ability to not focus on details, to extract concepts from our experiences and to relate those concepts to each other is what makes us humans unique. In animal experiments, it has been shown that memory is related to specific situations and contexts. In humans this is not the case. We are able to abstract from context and have conceptual memory. And that is the key to specifically human mental processes such as generalization or linking concepts to create new concepts. In short, that is the key to human cognition, to our intelligence

Neurotechnology case studies

Neurotechnology is transforming our understanding and treatment of neurological diseases, as well as the way we improve our cognitive and physical abilities. The following explores practical application cases from the experts attending the forum, from neural interfaces based on graphene nanotechnology to digital neurotherapy and rehabilitation using exoskeletons.

Graphene nanotechnology for high-density neural interfaces

Graphene nanotechnology is a new area of research that has the potential to revolutionize the field of neurotechnology. Graphene is a two-dimensional, very thin and strong material that has a number of unique properties that make it ideal for neuroelectronic applications. For example, graphene is an excellent **electrical conductor**, which means that it can be used to create devices capable of detecting and amplifying neuronal electrical signals. Besides, graphene is **biocompatible**, which means that it can be implanted in the body without triggering an immune reaction.

In recent years, graphene-based devices are being developed that can be used to create **high-density neural interfaces that are smaller, more efficient, and safer**. As these devices are developed and refined, they will have significant impact on neuroscience and neuromedicine. These devices are capable of recording the activity of hundreds or even thousands of neurons at a time, allowing researchers to study brain function with an unprecedented level of detail.

High-density neural interfaces have the potential to revolutionize the treatment of a number of neurological diseases. For example, these devices could be used to control the symptoms of epilepsy, Parkinson's and other neurological diseases. In addition, high-density neural interfaces could be used to restore brain function in people who have suffered a brain injury or neurodegenerative disease.

Specifically, the team made up by Carolina Aguilar, Chief Executive Officer & Co-Founder and Jose Antonio Garrido, CEO and Founder and Chief Scientific Officer of INBRAIN Neuroelectronics respectively, is working on the development of **graphene-based smart microdevices that can be implanted in the brain to treat neurological diseases**. These devices would be able to decode brain signals with high fidelity, allowing doctors to control disease symptoms and restore brain function.

Prof. Garrido explains the applications of graphene nanotechnology:

Discovering biomarkers for therapies: Parkinson's disease, Alzheimer's disease, epilepsy, neuropsychiatric disorders, ...

Neuroprostheses for motor or sensory disabilities

Helping scientists **to better understand the functioning of a normal and a diseased brain**

Presently, the great challenge with graphene technology is to make it accessible to the general public. At the experimental and scientific level, it is already proving very useful for medical specialists, but it still has to pass the regulatory and clinical acceptance hurdles before it can be used widely.

> **"Graphene nanotechnology may enable personalized neuroelectronic therapies"**
>
> **Jose Antonio Garrido**
>
> View video

Jose Antonio Garrido

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Digital neurotherapy

Digital neurotherapy is an emerging field that uses technology to treat neurological diseases. One of the most promising areas in this field is *brain-computer* interfaces (BCI). BCIs are devices that make it possible, on the one hand, to collect information on users' brain activity and, on the other hand, for the users themselves to control computing devices with their thoughts.

Professor Javier Mínguez, Professor and Director of Neurotechnology at the University of Zaragoza and Co-Founder of Bitbrain, has been working on the development of BCIs to treat neurological diseases for more than 20 years. In his talk, Professor Mínguez presents **software-based solutions that, through the use of artificial intelligence, are able to prevent, treat and monitor neurological diseases**, using a textile brain-computer interface, easily placed by patients themselves. Its main objective is to harness the power of artificial intelligence to prevent diseases and speed up medical treatments in common cases such as epilepsy, Alzheimer's, stroke and sleep disorders. The beauty of this innovation lies in the fact that it **allows part of the process of diagnosis, treatment and medical follow-up to be transferred directly to the patient's home**.

This solution is especially beneficial for people who suffer from chronic diseases, have impaired mobility or live in remote areas, where access to efficient medical services may be limited. In these cases, wearable technology becomes the only viable alternative for accessing adequate healthcare. Thanks to this tool, the aim is to improve the quality of life of patients by providing faster and more accurate care, reducing waiting lists and increasing the efficiency of the healthcare system.

One of the most promising examples of digital neurotherapy solutions developed by Professor Mínguez is the Bitbrain cognitive rehabilitation system. This system leverages a BCI to help people with brain injuries recover cognitive function. The system has been tested in clinical trials with positive results and is currently in development for commercial use.

Some additional examples of how digital neurotherapy is being used to treat neurological diseases:

- *Epilepsy:* BCIs may help reduce the frequency of seizures in people with epilepsy refractory to treatment.
- *Parkinson's disease:* They can also help improve mobility and coordination in people with Parkinson's disease.
- *Brain injuries:* Finally, they can help improve cognitive function in people with brain injuries.

Ver vídeo

Javier Minguez

Ver perfil

In addition, Bitbrain's textile BCIs, together with its software, can be used to **improve users' cognitive abilities**, even while they are asleep, notes Prof. Mínguez. This type of solution is being applied to patients with mild cognitive impairment.

Finally, digital neurotherapy **enables massive clinical studies over long periods of time**, as it is a non-invasive and patient-friendly technology. This will facilitate research and analysis of trends, patterns and correlations that may not be evident in current, much smaller studies.

Static magnetic field stimulation for Parkinson's disease

Static Magnetic Field Stimulation (SMF) is **a new non-invasive brain stimulation technique** that has the potential to revolutionize the treatment of Parkinson's disease. SMF uses a magnetic field to stimulate the brain, which can help improve symptoms of the disease, such as stiffness, slowness of movement and tremors.

Dr. Guglielmo Foffani, Researcher and Scientific Coordinator at HM CINAC, Group Leader at the National Paraplegic Hospital and Co-Founder of Neurek, presents a new SMF stimulation technique that is more effective and safer than existing methods. The new technique uses a stronger and more focused magnetic field, which allows for more precise stimulation of the areas of the brain that are involved in Parkinson's disease. In addition, the device that performs the brain stimulation is portable and easy to position.

Results from clinical studies have shown that the new SMF technique is effective in improving the symptoms of Parkinson's disease. In a recent study, patients who received SMF stimulation experienced a significant reduction in rigidity, slowness of movement and tremors. Patients also reported an improvement in their quality of life.

Guglielmo Foffani

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As with all noninvasive brain stimulation techniques, we do not fully understand the exact mechanisms by which static magnetic field brain stimulation produces its effects, but evidence suggests that modulation of the ion exchange across the membrane may be accountable for its physiological effects at the cellular level, says Dr. Foffani.

In addition to Parkinson's disease, SMF stimulation has also been tested to treat other brain disorders, such as epilepsy, depression and Alzheimer's disease. The results of clinical studies have been promising, and SMF stimulation is being developed to offer effective and sustainable treatments over time for the aforementioned brain disorders.

Mª Cruz Rodriguez

Ver vídeo

Clinical application of HIFU in neurological disorders

HIFU (High-Intensity Focused Ultrasound) is a minimally invasive technique that uses high-intensity ultrasound to treat a variety of neurological disorders. HIFU can be used to **injure and destroy abnormal brain tissue, which improves the symptoms** of certain neurological conditions.

Mª Cruz Rodriguez, Director of Neurology and Neurosciences at the Clínica Universidad de Navarra is an expert in the clinical application of HIFU in neurological disorders. HIFU, Dr. Rodriguez tells us, treats the symptoms of Parkinson's disease, such as tremor, rigidity and clumsiness, and problems with balance and coordination. It focuses on the subthalamus of the brain, a region involved in movement, using high-intensity ultrasound to injure and shrink the affected neurons, thus improving symptoms.

Prior to the application of HIFU, one possible line of treatment was pharmacological, but it did not alleviate the symptoms of Parkinson's well enough for patients to lead a normal life with an adequate quality of life. The other possibility was using electrical deep brain stimulation, which required the installation of a sizable electrical battery in the patient's chest, the implantation of electrodes in the patient's brain by surgery, and the connection of the two parts by external wires.

HIFU can also be used to treat other neurological disorders, where deep brain stimulation with electrodes has been applied, including epilepsy, pain disorders, depression or obsessive-compulsive disorder (OCD).

Brain dynamics and modeling

Whole brain modeling opens the door to causal understanding of neuroimaging data. The aim is to understand the underlying mechanisms of the human brain in health and disease with a model that captures sufficient detail to explain **how function arises from the underlying anatomy and can be shaped by neuromodulation**. ICREA Research Professor and Professor at Pompeu Fabra University, Gustavo Deco, has been studying large amounts of brain imaging and based on that, is exploring how brain activity changes. He has developed a new way of understanding the brain that is inspired by thermodynamics, which helps us to see how different parts of the brain interact with each other and how these interactions change under different circumstances. **Computer simulation of this model of the brain could predict and recommend the best treatment for certain neurological diseases or coma states.**

The model created by Prof. Deco allows us to characterize the dynamic causal mechanisms underlying different brain states. In other words, this technique gives us a **detailed view of how and why the brain moves between different states**, providing a deeper insight into its functioning.

In addition, Professor Deco notes that neurostimulation-driven transitions between brain states can be implemented *in silico*, i.e., using computer simulations. These *in silico* investigations could identify crucial nodes for forcing transitions between brain states, which could have applications in the treatment of conditions such as coma, stroke and neuropsychiatric diseases. In fact, going forward, Prof. Deco raises the possibility of applying his model to **predict the best treatment for disorders of consciousness and neuropsychiatric disorders**. This could revolutionize the way we approach the treatment of these diseases, allowing for **more personalized and effective interventions based on a deeper understanding of brain dynamics** and how it can be modified.

Finally, Prof. Deco mentions two projects that are being developed by applying whole brain modeling: one to **understand the cognitive losses associated with aging** and what mechanisms would be the most effective to reverse these losses, called The Aging Imageomics Study, and another to better understand the coma state and study mechanisms that can help to exit this state.

Gustavo Deco

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Brain-computer interfaces and virtual reality

Brain-computer interfaces (BCIs) and virtual reality (VR) are converging to create **immersive, personalized experiences** that can have a significant impact in numerous fields, from medicine to entertainment.

Mavi Sánchez-Vives, a leading researcher in the field of neuroscience and technology, has been exploring the potential of these technologies for more than 20 years, currently in the Event Lab (Experimental Virtual Environments in Neuroscience and Technology) that she co-directs. Her work focuses on **how virtual reality can be used to modify our perception of the body and, in turn, how this can change the way our brain processes information.**

Immersive virtual reality can be used to create a "virtual body" that can be modified in various ways. For example, the size, shape, or even the species of this virtual body can be changed. These changes can have a **significant impact on the way we perceive our own body and the world around us**. On the other hand, brain-computer interfaces allow direct communication between the brain and external devices. This can be used to control the virtual body in virtual reality, creating an immersive experience that can be customized for the individual.

Mavi Sánchez-Vives

Ver vídeo

Prof. Sánchez-Vives highlights **four applications of these technologies in the field of health and social welfare:**

- For **pain modulation**, allowing patients to experience pain relief through immersion in a virtual environment.
- For **physical rehabilitation**, allowing patients to practice movements and skills in a safe and controlled environment.
- For **behavioral rehabilitation**. For example, they can be used to treat phobias and anxiety disorders. In this area, it is also being applied to treat obesity problems.
- For the **improvement of empathy and social skills**. Beyond changing behaviors due to neuropsychiatric disorders, **immersive virtual reality (avatars)** can be **used to improve our social skills and help eliminate prejudices and biases**. This is what the startup founded by Sánchez-Vives, kiin, is dedicated to. It has created programs such as DiVRse, which addresses **discrimination** based on race, gender and gender identity and is already being used in several large corporations. Or VRespect. ME, to raise awareness and correct behavior that is harmful to others, such as **male violence**. This tool is already being used for the social rehabilitation of sex offenders in several European prisons and is being developed within the framework of the EU project VR per GENERE (Gender Violence in Europe based on Neuroscience of Embodiment, PeRspective and Empathy). This initiative focuses on the deployment of prevention and rehabilitation tools based on immersive virtual reality to reduce gender-based violence.

Neurotechnology and rehabilitation using exoskeletons

Neurotechnology, combining brain-computer interfaces (BCIs) with mechanical-electronic devices (exoskeletons), opens a promising field for motor rehabilitation.

Ander Ramos-Murguialday, Neurotechnology and Translational Science Leader at TECNALIA and the University of Tübingen, is a pioneer in this field. His work focuses on the use of exoskeletons for the rehabilitation of stroke patients.

Ander Ramos-Murguialday

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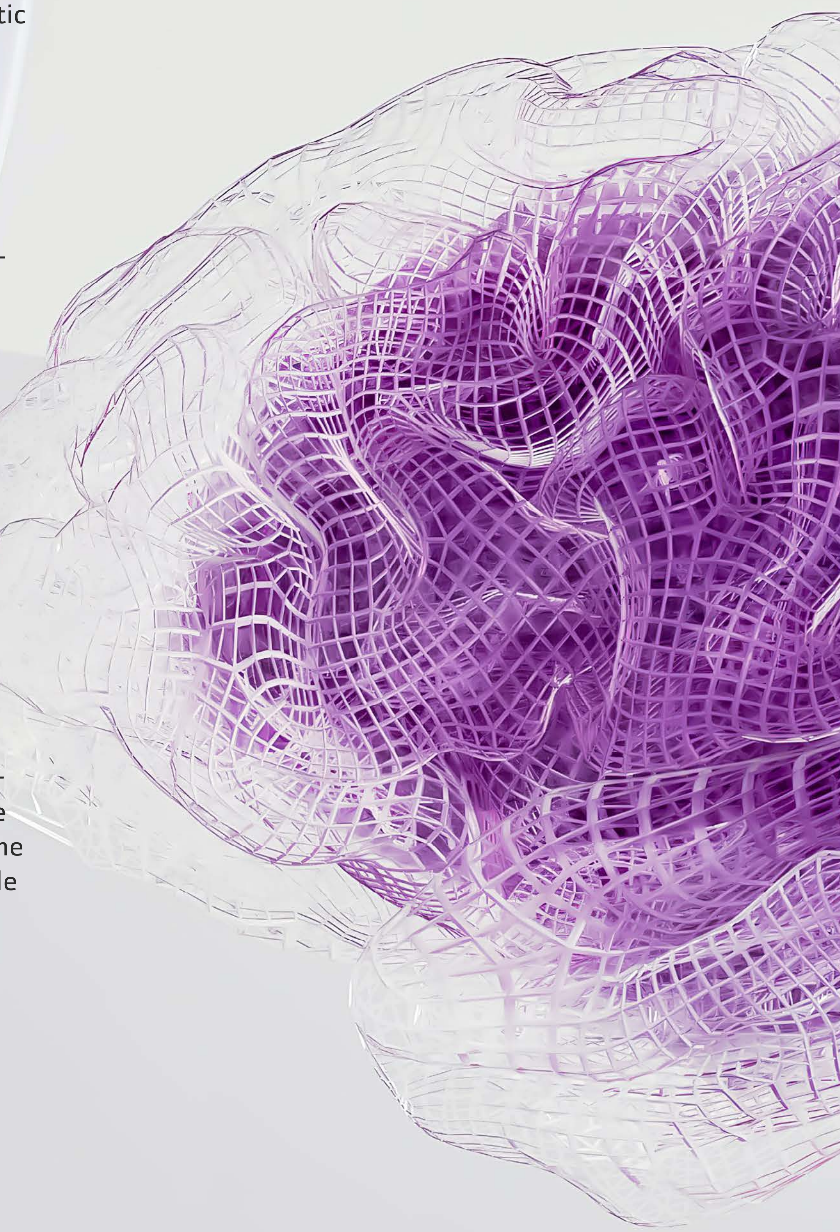
A stroke can cause a range of physical problems, including weakness or paralysis in a part of the body, and rehabilitation aims to help patients regain as much function as possible. Exoskeletons are robotic devices that worn over the human body and help users move. In the case of post-stroke rehabilitation, an exoskeleton can be used to help patients move parts of the body that have become weakened or paralyzed.

Ramos-Murguialday and his team are using neurotechnology to improve the effectiveness of these exoskeletons: using brain-computer interfaces, they capture signals from the patient's brain that indicate the intention to move. These signals are used to control the exoskeleton, allowing the patient to move in a more natural and fluid way, facilitating neuroplasticity and motor recovery.

In addition, the use of exoskeletons in rehabilitation provides valuable feedback for patients and therapists: sensors in the exoskeleton can collect data on the patient's movement, which is used to assess progress and adjust treatment.

So far, the brain-computer interfaces used for motor rehabilitation are invasive (i.e., implants in the brain). Non-invasive techniques do not, for the time being, have the resolution or signal quality suitable for this type of solution.



AI and Neuroscience Research Centers

Advances in artificial intelligence (AI) and neuroscience research are driving the creation of powerful knowledge and technology ecosystems. In Europe and particularly in Spain, two research centers stand out for their contribution to this emerging field: EBRAINS and CiTIUS (Singular Center for Research in Intelligent Technologies at the University of Santiago de Compostela—USC).

At a European level, EBRAINS is an open research infrastructure created from the EU-funded Human Brain Project (HBP) that brings together a wide range of data and tools for brain and neuroscience-related research. Viktor Jirsa, Human Brain Project Scientist and Scientific Director of EBRAINS, explains that this initiative has been instrumental in the development of new neuroimaging and neurocomputing techniques, and has contributed to the advancement of our knowledge about the brain. EBRAINS is revolutionizing the way neuroscience research is conducted, changing the culture of research from fragmented efforts in individual labs to **integrated research on platforms**. The ultimate goal: to **better understand the brain and improve brain health and technology**, says Prof. Jirsa.

An example of what is being achieved with EBRAINS is the tool *The Virtual Brain*, a virtual brain model (we could say, a digital twin of the brain), which is used for research and clinical decision making. This tool is already being applied to the study of patients with epilepsy.

In addition to better understanding epilepsy and proposing new treatments, *The Virtual Brain* is being used to study **multiple sclerosis** and to **improve brain stimulation techniques**.

In Spain, the Singular Center for Research in Intelligent Technologies at the University of Santiago de Compostela (CiTIUS) is leading the way in AI research. Under the leadership of Senén Barro, Professor of Computer Science and Artificial Intelligence and Scientific Director of the center, it has established itself as a center of excellence in the development and application of smart technologies. Its work spans a wide range of disciplines, from robotics and computer vision to machine learning and artificial intelligence and is driving innovation in a variety of sectors.

Prof. Barro explains that there are more and more scientific studies using AI in the field of neuroscience and neurotechnology. In fact, at the next edition of the ECAI (*European Conference on Artificial Intelligence*), to be held in Santiago de Compostela in 2024, this will be one of the main topics.

Viktor Jirsa

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CiTIUS is developing four projects that have potential applications in neurotechnology:

Design and develop a 1 mm^2 solar cell and a power management unit (PMU) on the same substrate to power wearable or implantable devices, which could be a power source for BCIs.

Intelligent multispectral vision system with integrated low-power neural computing, which could be implanted in visually impaired patients.

A new immersive virtual reality system that could be used for applications of the type mentioned above by Prof. Sánchez-Vives. One step further, says Prof. Barro, this virtual reality system can be used as a research and training tool for scientists, as a substitute for psychedelic substances as a therapy that uses self-transcendence to treat anxiety, depression and drug addiction, and as a tool for the design of new molecules.

Creation of **federated learning** tools (often referred to as collaborative learning), which is a decentralized approach to training machine learning models. It does not require an exchange of data from client devices to global servers. Instead, raw data from edge devices is used to train the model locally, which increases data privacy. Prof. Barro notes that this tool is being applied for early diagnosis of Alzheimer's and Parkinson's disease.

Senén Barro

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These two research centers represent the frontier of AI and neuroscience research in Europe and Spain. Through their work, they are contributing to the creation of a research and development ecosystem that holds the promise to transform our understanding of the human brain and the possibilities of artificial intelligence.

In addition, in 2022, the launch by the Government of Spain of the National Neurotechnology Center, Spain Neurotech, a pioneer in Europe in the development of technological tools based on the fundamentals of the human brain, made headlines. A project of the Ministry of Economic Affairs and Digital Transformation, the Community of Madrid and the Autonomous University of Madrid that aims to promote a network of specialized public and private centers throughout the territory through which to advance research into chronic diseases in their initial stages, as well as neurodevelopmental disorders, autism spectrum diseases, Parkinson's, Alzheimer's, depression, sleep disorders, circadian rhythm pathologies or acute brain damage.

Outside Europe, there is another noteworthy initiative: BRAIN (*Brain Research Through Advancing Innovative Neurotechnologies*), created in the USA to accelerate the development of innovative neurotechnologies. Among other things, BRAIN aims to create a revolutionary new dynamic image of the brain that, for the first time, shows how individual cells and complex neural circuits interact in both time and space.

From the laboratory to the market

Neurotechnologies are emerging as an innovative field with the potential to revolutionize the way we interact with the brain and treat neurological disorders. Research centers and universities, while advancing in the discovery of new solutions, are creating a network of knowledge and technology transfer that often spins off into start-ups supported by public-private collaboration.

Kristina Dziekan, as a non-executive member of the ONWARD Board, advocates for policies that foster equitable access to markets for promising startups in the field of neurotechnologies. Her experience and strategic vision have led her to promote collaboration between the public and private sectors and foster the development of fair and efficient neurotechnology ecosystem and regulatory frameworks.

Kristina Dziekan

Ver vídeo

In Europe, with its diversity of healthcare systems and regulations, this process is even more complex. Market access is not only about regulatory approval, but also about ensuring that **innovations are adequately funded and integrated into patient care protocols**. A key challenge in Europe is how to make the technologies commercially viable, i.e., how to get them paid for and reimbursed by insurance companies or governments. While there may be similar technologies already on the market, new innovations, such as deep brain stimulation, must demonstrate additional benefits to be considered for reimbursement. For example, the company Onward is developing spinal cord stimulation technology for patients with spinal cord injuries. With the emergence of brain-computer interfaces and other advanced neurotechnologies, it is essential to establish clear categories and standards for reimbursement. Without clear guidance, payers and healthcare providers may find themselves at a crossroads, not knowing how to integrate these innovations into treatment protocols.

One proposal is to start in one given country, such as Spain, and build a market access prototype, similar to what DIGA did in Germany with digital health. This prototype could inspire all of Europe. However, for this process to be effective, it is essential to involve all relevant stakeholders, including payers and patients.

A challenge for startups is balancing the desire for growth with societal impact. Collaboration between companies and the public sector can be slow and resource-consuming, but it is essential to ensure sustainable and beneficial market access. The case of DIGA in Germany serves as an example of how digitalization can facilitate market entry. For startups in Europe, the choice between targeting the U.S. market or staying in Europe and working with country-specific regulations is crucial.

Spanish startups in neurotechnology

Three Spanish startups are leading the arrival of these technologies to the market: Neuroelectrics, Bitbrain and INBRAIN Neuroelectronics. Their pioneering work in brain stimulation, brain-computer interfaces and implantable neurotechnology promises to open up new possibilities in the treatment of neurological diseases and improve our understanding and connection with the human brain. What challenges have they faced in going to market? What are the keys to their success? Below, some of the protagonists explain.

Neuroelectrics, co-founded and directed by Ana Maiques, is dedicated to developing **non-invasive solutions for brain stimulation and neurological monitoring**. They use technologies such as transcranial direct current stimulation (tDCS) and electroencephalography (EEG) to offer innovative, non-pharmacological treatments for neurological conditions such as epilepsy, depression and chronic pain.

In addition, Neuroelectrics has developed a portable device that allows real-time monitoring and diagnosis of brain activity, which facilitates research and the development of personalized therapies. One of its competitive advantages: the device can be worn by the patient at home, it monitors their brain activity, and it can perform brain stimulation based on their activity readings as well.

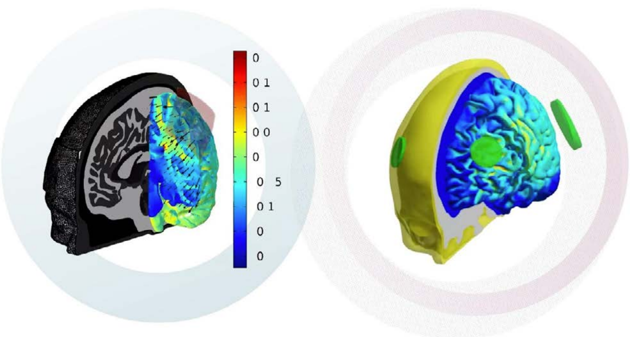

Imagen de la web: https://www.neuroelectrics.com/

Ana Maiques

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This startup was founded by two very different and complementary profiles, Giulio Ruffini, the scientist, and Ana Maiques, the entrepreneur. Ana points out that the success of Neuroelectrics has a lot to do with this two-sidedness, where each brings the best of themselves, and the necessary convergence of objectives takes place. They are two cultures (scientific and entrepreneurial) that have to understand each other and move forward with the same vision: to **bring innovative neurotechnology solutions for the benefit of patients and healthcare systems**.

Another key to success is having very diverse talent from all over the world.

Founded in Barcelona, it is now based in Boston, USA, from where it has launched two trials with the FDA—the U.S. government agency responsible for the regulation of food, drugs, cosmetics, medical devices, biological products and blood derivatives—one to treat patients with epilepsy and the other for patients with severe depression. The results are promising. For example, in the case of patients with epilepsy, it has been shown that the use of the equipment for 20 minutes a day for ten days in a row reduced seizures in patients by 50 percent.

María López

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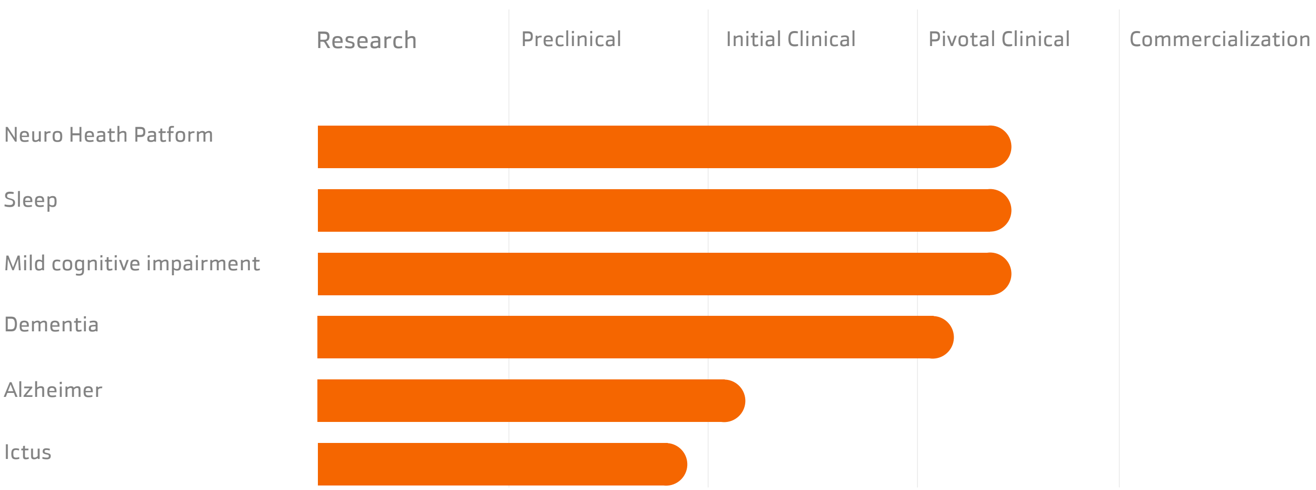
The next step, in addition to continuing to bring its device to market, is the creation of **digital twins of the patients' brains** that would allow treatments to be adapted by means of simulations before applying them in real life.

Bitbrain, co-founded and led by María López, specializes in brain-computer interfaces and applied neurotechnology. Its technology includes **portable neuro-recording and stimulation devices, as well as advanced software and algorithms for the analysis of brain signals**. These products enable real-time monitoring and interpretation of brain signals, opening up a wide range of applications in fields such as research, mental health and rehabilitation. The leadership model of this startup is similar to that of Neuroelectrics, where **Javier Mínguez** serves as Chief Scientific Officer. Prof. Mínguez had created very advanced prototypes of brain-computer interfaces for neuroprosthetics and robot control from the University of Zaragoza, which were widely covered in the media and generated a lot of interest from both potential patients and the scientific community. As a result, María López convinced him to create a spin-off from the University to bring this technology to the market. Since then, ten years ago, they have been researching and developing solutions and devices for this purpose. The peculiarity of this startup is that they have decided not to seek venture capital funding until they have their products and solutions perfectly ready to go to market. They do not want pressure from investors while developing their solutions. In the meantime, they are funded through research projects and collaborations with other research centers. As of today, they are in up to six clinical trials in Spain and creating a network of startups and research centers to use their Elevvo Neuro Health Platform.

INBRAIN Neuroelectronics, co-founded by José Antonio Garrido, focuses on implantable neurotechnology. The company develops **high-tech graphene-based brain implants that can interact directly with brain tissue to treat neurological disorders and improve cognitive functions**. These implants are designed to be safe and durable and use advanced materials and cutting-edge technology to ensure optimal performance.



For Prof. Garrido, **the first key to bringing a technology to market is rigorous research** in laboratories. In fact, INBRAIN Neuroelectronics is a byproduct of his activity as ICREA Research Professor and leader of the ICN2 Advanced Electronic Materials and Devices Group, which explores new electronic materials, such as graphene and other 2D materials, and their potential in electronic and bioelectronic applications. From the point of view of research, if you want to bring a product or solution to the market, it is necessary to **create a suitable professional team for it**, outside the academic research environment, says Prof. Garrido, who explains how, presenting his project to a venture capital fund, he met the person who was finally able to lead the startup, Carolina Aguilar, its current CEO.

INBRAIN faces different regulatory challenges than Neuroelectrics and Bitbrain, because it offers an invasive solution. At the European level, there are not even any rules or regulations on how implantable nanomaterials should be treated in human tissues or organs. On the other hand, Prof. Garrido points out, INBRAIN's North American competitors have a certain edge because it is easier to obtain financing from specialized venture capital funds there.

These three Spanish startups are examples of the effervescent ecosystem of neurotechnology startups worldwide. Some international startups to get to know, in addition to those mentioned in this report (iota Biosciences, Neurek, kiin) are:

Brainsway and **Neuronetics**, which develop solutions and devices for transcranial magnetic stimulation (TMS).

NeuroSky, which develops sensors for measuring brain activity.

Neofect, which develops devices for neuromuscular rehabilitation.

Neuralink, which develops implantable brain-computer interfaces (BCI). Very recently, it has announced approval from the U.S. Food and Drug Administration (FDA) for **human studies of its brain implants.**

Paradomics, which also develops implantable brain-computer interfaces (BCI) with very high data transmission speed.

Kernel, which, through the application of AI tools, develops new biomarkers.

One of the biggest challenges for neurotechnology startups is attracting and retaining global talent, according to Ana Maiques. To this end, **promoting the growth of an entrepreneurial ecosystem in neurotechnology** could be one of the keys, as Prof. Garrido points out. Attracting funding would follow quite naturally in a solid, blossoming ecosystem. And as for funding, although today North American startups have up to four times more funding than European startups, this gap is being bridged with initiatives such as the one launched by the European Innovation Council (EIC), which has 1.6 billion euros in 2023 to invest in the most innovative startups to turn them into scaleups, many of them into technology transfer startups (Deep Tech). In Spain, venture capital funds specialized in technology transfer are already being set up, such as Grow Venture Partners, Barcelona Deeptech Fund or TECNALIA Ventures, in addition to the managers that were already doing so, but not in a specialized way, such as JME Ventures.

These initiatives can change the so far scarce European capacity to convert scientific and technological developments into business, compared to the U.S. and Asia. Grace Xin Ge, trustee of the Bankinter Foundation of Innovation, points out two challenges facing technology-based startups in Spain and, in general, in Europe: on the one hand, there is a lack of professional experience of profiles capable of accelerating the growth of these startups and, on the other hand, there is not enough ambition to seek the globality of the products and solutions that are created.

Spanish technical universities and research centers are starting to take technology transfer seriously, which has long been an item on our to-do list, being the laggards behind other European countries and the U.S. So, in the near future, we will see the creation of more *spin-offs* dedicated to neurotechnologies and also other basic technologies, such as quantum computing. Additionally, European applied research and technology development centers, such as Tecnalia, are more aware of the relevant role they can play in accelerating technology transfer.

Grace Xin Ge

Go to profile

2

Other technologies for human enhancement

2

Other technologies for human enhancement

Gene editing and synthetic biology

The ability to read DNA, first achieved with the Human Genome Project, has had a major impact on our understanding of how life works and how disease occurs. In particular, it has changed our approach to how to optimize cancer therapy, allowing us to select the right drug for each type of cancer.

With CRISPR technology, it is now possible to make genetic modifications by editing the DNA sequence. CRIPSR has enormous potential for medical applications, especially for the treatment and cure of genetic diseases, which are often due to minimal changes in the DNA sequence, and this technique makes it possible to correct them. Francis Collins, principal investigator and former Director of the US National Institute of Health, well known for his leadership of the Human Genome Project, illustrates the benefits of gene editing with advances in the fight against progeria, an extremely rare and devastating genetic disease that causes accelerated aging in children. Scientists have identified the mutation responsible for progeria, known as the LMNA mutation, which has led to a greater understanding of the underlying mechanisms of the disease. This has led to the development of therapies specifically aimed at counteracting the effects of this mutation, such as the use of farnesyltransferase inhibitors and drugs that stabilize the cell nucleus.

Francis Collins

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In addition, gene editing has shown promise in the treatment of sickle cell disease, the first known molecular disease. Currently, there are two gene-editing protocols for this disease under review by the FDA, says Dr. Collins. And it's just the beginning: "**There are 7,000 genetic diseases that could be cured or improved using gene editing**," says Dr. Collins.

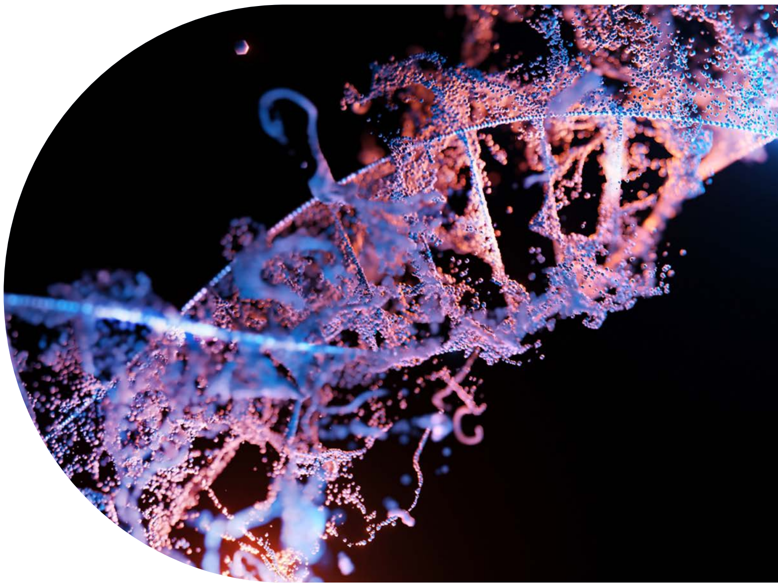
Gene editing is a topic that generates enthusiasm and, at the same time, requires serious reflection on its various applications. Dr. Collins says that, despite these positive developments, gene editing also raises ethical and moral concerns, especially when it comes to modifying human embryos. Collins cites the case of a scientist in China who modified embryos to reduce the likelihood of HIV infection. This has raised **concerns about the safety and ethical implications of modifying the human genome that may affect future generations**. Collins emphasizes that, although gene editing in animals is advancing and providing valuable learnings, the international community generally agrees that gene editing should not be performed in humans. However, there is an ongoing debate as to whether this moratorium should be permanent or whether there are circumstances under which it could be allowed.

Regarding **gene editing for the enhancement of human capabilities**, Dr. Collins points out that innumerable questions arise that must be addressed from a holistic perspective: social, moral, legal, scientific, anthropological.

In the meantime, there must be major advances in gene-editing technologies, especially in how they will be practically applied to humans. A very positive example pointing the way forward is the cure of sickle cell disease with CRISPR, where all the symptoms of a disease that was thought to be incurable, disappear.

> **"There are 7,000 genetic diseases that could be cured or improved using gene editing"**
>
> **Dr. Collins**

Finally, Collins stresses **the importance of clear and accurate communication about gene editing and its potential applications and risks**. At a time when confidence in science has declined, scientists have a responsibility to work to regain the general public's trust and ensure that their research is conducted for the benefit of humanity.



RNA and human enhancement: New frontiers in nanomedicine

The use of RNA is revolutionizing nanomedicine and human enhancement. Its use in **gene therapies; regenerative medicine and vaccines** make it possible to treat genetic diseases, regenerate tissues and develop faster and more adaptable vaccines. The potential of RNA in human enhancement is promising and will continue to expand in the future, thanks to research and achievements in RNA-carrying vehicles. So says Dr. Mª José Alonso, Professor of Biopharmaceutics and Pharmaceutical Technology at the University of Santiago de Compostela.

Although much has been said about human enhancement and gene editing, it is RNA that has revealed practical innovations that are already applicable. The definition of "human enhancement" has been the subject of debate, but Dr. Alonso describes it as an effort to improve human characteristics, abilities or functions. Since diseases are mostly the result of biological dysfunctions, often related to malfunctioning genes, being able to give the body the tools it needs to cure them is part of this definition. What is revolutionary in medicine today is that it is no longer just about addressing the symptoms of a disease but going directly to its root cause. Rather than simply treating, it now seeks to **allow the body to repair itself**. This perspective is a dramatic departure from traditional medicine, says Dr. Alonso.

Mª José Alonso

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In terms of practical applications of RNA, it is necessary to differentiate between mRNA vaccines and RNA-based therapies. While mRNA vaccines, such as those developed for COVID-19, introduce genetic information into our body so that it produces the desired protein, RNA-based therapies directly address the cause of the disease, either by silencing a defective gene or by introducing RNA that instructs the body to produce a curative protein.

A crucial aspect that Dr. Alonso highlights is the integration of various technologies. While genomics and proteomics identify defective genes, and biotechnology enables the production of RNA and proteins for treatments, **nanotechnology plays an essential role in the effective delivery of these therapies**. Nanoparticles are critical for transporting RNA to the right place in the body. These nanoparticles, some of which have been developed in Dr. Alonso's laboratory, have been essential to the efficacy of vaccines, especially COVID-19 vaccines. Although COVID-19 vaccines seemed to have been developed at breakneck speed, they were actually based on decades of research. Nanoparticles, such as liposomes, have been around since the 1970s, and RNA formulations for influenza vaccines were being developed as early as the 1990s.

And how are these technologies benefiting people today? In addition to COVID-19 vaccines, there are treatments on the market for rare diseases and hundreds of clinical trials underway to treat other diseases. Dr. Alonso also highlights **research in areas such as the delivery of RNA to the brain to treat diseases such as Alzheimer's and glioblastoma, as well as the development of new antibiotics and cancer therapies**.

Ultimately, **the future of medicine lies in the integration of genetics, nanotechnology and biotechnology**, which promises to revolutionize the way we treat and prevent disease.

AI for antibiotic discovery

Drug development is a slow and expensive process, with an estimated cost of more than $2 billion per drug. It can take more than a decade to develop a drug and three to six years to discover preclinical candidates. However, the increase in computing power, the ability to generate and process large amounts of data, and artificial intelligence (AI) tools, promise to shorten timelines and costs exponentially.

César de la Fuente, Assistant Professor to the President at the University of Pennsylvania, and his team have specialized in the search for new AI-driven antibiotics that can **over-come antibiotic resistance**—the ability of a microorganism to resist the effects of an antibiotic. According to Prof. De la Fuente, by 2050, deaths caused by antibiotic resistance could exceed deaths from cancer.

To address this problem, his team uses machine learning to design new antibiotics. They emulate the evolutionary process by encoding small proteins in the computer and allowing the machine to run evolution *in silico*. After designing these molecules in the computer, they synthesize them chemically and test their efficacy in the lab. The team he leads has already synthesized some 55 peptides that, when tested against popular drug-resistant microbes, such as the germ responsible for staph infections, have been shown to prevent the bacteria from replicating.

César de la Fuente

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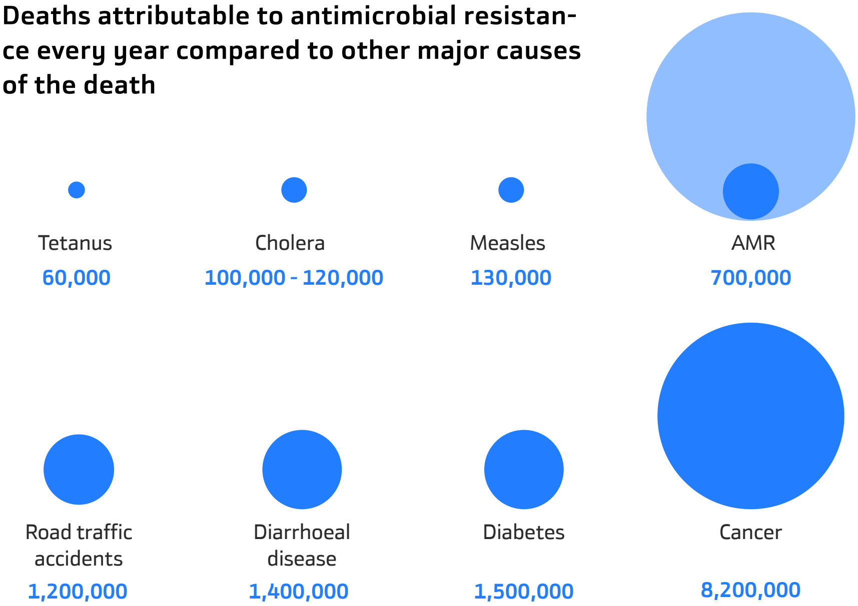
Deaths attributable to antimicrobial resistance every year compared to other major causes of the death



Source: Review on Antimicrobial Resistance 2014

On the other hand, and also using machine learning algorithms, they search the human genome for peptides that fight microbes. For the design of the algorithms, they are inspired by image and voice recognition algorithms: these algorithms identify molecular patterns that could be potential antibiotics. De la Fuente and his team have scaled up this process to analyze entire proteomes, discovering "cryptic peptides" with antimicrobial properties. These discoveries pave the way for the creation of antibiotics based on natural peptide sequences from the human proteome, which are called encrypted peptides—different from the antimicrobial peptides described above, although with very interesting properties too.

In the process of creating new antibiotics, they have discovered that **AI-generated antibiotics act differently from conventional antibiotics**, affecting the bacterial membrane in a unique way. Moreover, these antibiotics have been shown to be effective in preclinical experiments with mice.

The team has also explored proteomes of our closest relatives, Neanderthals and Denisovans, discovering differences in antibiotics across evolution. These findings highlight the potential of AI in drug discovery and how it can reveal previously unknown molecules and mechanisms.

Throughout this scientific research process, De la Fuente emphasizes the importance of involving bioethicists and considering the implications of releasing certain data sets to the public: a multidisciplinary approach and careful consideration of ethical and safety implications are necessary.

Reprogramming the bioelectrical software of life

Bioelectrical patterns, the electrical signals produced in living organisms, play a fundamental role in tissue development and regeneration.

Bioelectrical pattern reprogramming refers to the understanding and manipulation of the "intelligence" of biological systems. Although these systems are genetically encoded, their plasticity allows them to adapt to different circumstances. Xenobots, for one, are created from frog skin cells, and can replicate and form new generations.

Michael Levin, Professor of Biology, Distinguished Professor of Philosophy and Humanities and Professor of Biomedical Engineering at Tufts University, studies anatomical and behavioral decision making at multiple scales of biological, artificial and hybrid systems. According to Prof. Levin, **bioelectrical patterns are like "software" that guide the form and function of organisms**.

Levin has conducted pioneering research in the field of bioelectrical biology, demonstrating that **bioelectrical patterns can be manipulated to induce changes in the form and function of organisms**. The purpose of his research is to understand the abilities of cellular collectives to form large-scale patterns. This links with synthetic biology, which goes beyond traditional biology. A human being, for example, starts as a cell and transforms into a complex being thanks to the collective intelligence of cells. In the future, the hope is to develop an "**anatomical compiler**" that will enable scientists to **design and build specific biological structures, with applications in regenerative medicine**.

> **If you change the bioelectrical code, you change the whole organism**
>
> **Michael Levin**
>
> Ver vídeo

One challenge is to understand the intelligence of cellular collectives. These once independent cells can work together to achieve complex goals. Research has shown that **organisms can reprogram themselves through electrical signals**. For example, the transformation of a tadpole into a frog was thought to be a fixed process, but experiments have shown that they can adapt to different configurations. These adaptations are based on electrical signals that cells have used since ancient times.

Another experiment conducted by Prof. Levin and his team revealed that, by altering electrical patterns in tadpoles, intestinal cells could form an eye. This indicates that **the information to create supracellular structures is not only in genetics but can be activated by electrical signals**. One experiment with planaria has sent shockwaves: it was found that bioelectrical signals determine how they reconstruct themselves if they are split in half. When reprogrammed, two-headed planarians can be obtained that remember this condition in future regenerations.

These findings have major implications for medicine and bioengineering. It has been discovered that **beyond genetics, bioelectrical patterns can influence the development of organisms**. For example, some species can develop characteristics of others without genetic changes. One example is the oak tree, which can form structures called gills upon receiving signals from a parasite.

This concept of reprogramming is also essential to understand the difference between healthy and **cancer cells**. Cancer cells act independently, but **through bioelectrical reprogramming, they could be influenced to behave in a healthy way**. The medicine of the future could combine traditional approaches with strategies derived from this innovative branch of science that discovers that **cells have a collective intelligence that allows them to adapt to new situations.** Prof. Levin's theory has significant implications in fields such as regenerative medicine and tissue engineering. By understanding and manipulating bioelectrical patterns, **innovative therapies** could be developed **to regenerate damaged tissues, treat diseases and improve the human body's healing ability**.

Harnessing evolution and resilience networks to reverse diseases

How can biological systems adapt and recover from disorders or diseases? How can we use this knowledge to develop effective treatments?

Living organisms have inherent mechanisms of resilience and plasticity that can be harnessed to restore normal function in the event of disease. These mechanisms have developed over millions of years of evolution and allow organisms to adapt and respond to changes in their environment.

This is the field of expertise of Mauro Costa-Mattioli, Director of the Memory and Brain Research Center and Associate Professor of Neuroscience

Mauro Costa-Mattioli

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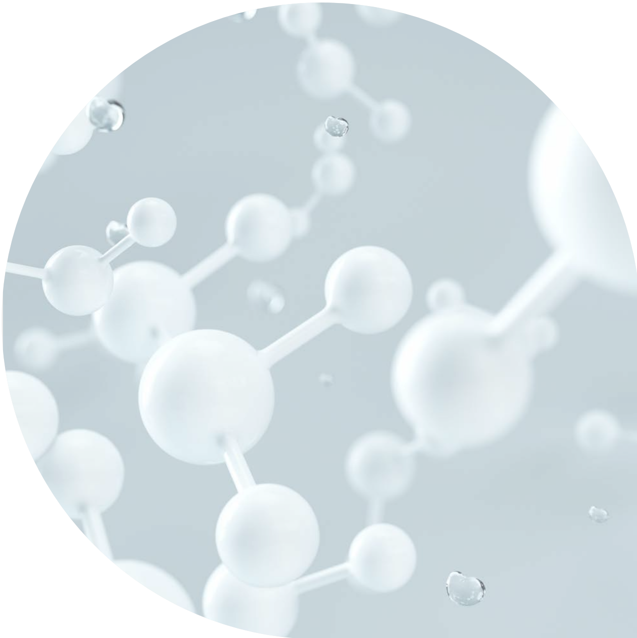
at Baylor College of Medicine and Principal Investigator of Altos Labs. Rather than focusing solely on identifying and correcting specific genetic defects, Costa-Mattioli's approach is based on the idea that by understanding how resilience networks function in the brain and other biological systems, one could identify therapeutic interventions that enhance these networks and promote recovery and restoration of normal function. This could involve the use of drugs, gene therapies, or other strategies to modulate the activity of resilience networks and promote disease reversal.

Two emerging concepts, resilience and the microbiome, are redefining our understanding of health and disease. Resilience refers to the ability to resist and adapt to adverse conditions. Inspired by the story of Prometheus, who defied the gods to benefit humanity, researchers seek to **understand how resilience may be key to reversing disease**. Rather than focusing on specific diseases, the focus is on understanding resilience at a biological level. Health is viewed as an interconnected system, from cells and microbes to entire organs. Any imbalance in this system can lead to disease.

> **Disease is a progressive failure in the homeostasis and resilience of the system. Its prevention or cure consists of repairing that failure**
>
> **Mauro Costa-Mattioli**



A particularly interesting area of research is **memory formation**. A factor has been identified that determines the conversion of short-term memories into long-term memories. In addition, a molecule has been discovered that can enhance memory in both healthy and diseased animals.

Then, the microbiome, the set of microbes that cohabit our body, also plays a crucial role in curing diseases. Prof. Costa-Mattioli's team discovered that the lack of a specific microbe, Lactobacillus Reuteri, in mice with autism spectrum disorder (ASD) affected their social behavior. By reintroducing this microbe, they were able to reverse this deficit. This microbe acts by inducing the production of oxytocin, a hormone associated with social reward. The true revolution lies in the fact that these findings are not limited to animal models. A clinical trial in Italy showed that administering Lactobacillus Reuteri to children with ASD could improve their social behavior. This suggests that **the microbiome may have a direct impact on brain function**.

The future of medicine could lie in the development of synthetic bacteria or advanced probiotics that promote health. The possibility of identifying specific metabolites produced by these microbes or creating foods that promote beneficial bacteria is also being explored.

The socio-political challenges of gene editing

While scientific progress should benefit all humankind, we find ourselves in a socio-politically fragmented world with a clear lack of international norms and regulations. As far as gene editing is concerned, the problem is compounded by the ethical and human rights implications it entails.

Joy Zhang, Professor of Sociology, Founding Director of the Center for Global Science and Epistemic Justice at the University of Kent, illustrates the lack of international regulation with the flourishing of gene editing initiatives in countries such as Honduras, where there is very lax legislation in this regard. Montenegro showcases another viewpoint, where people are coming together to create a new jurisdiction to promote *biohacking* and accelerate the development of drugs that slow down or reverse aging.

Prof. Zhang highlights the **challenge of global governance over gene editing**. As science and technology transcend national boundaries, it is essential to establish international standards and regulations for gene editing. However, reaching a global consensus may be difficult due to cultural and ethical differences. Meanwhile, cases such as that of He Jiankui, who created genetically modified human embryos using CRISPR, continue to shock the scientific community and society.

Another major challenge is equitable access to these technologies. Although gene editing has the potential to improve human health, its use may be limited to those who can afford it, exacerbating existing inequalities in health and well-being. Prof. Zhang emphasizes the need for policies that ensure equitable access to gene editing technologies.
In addition, gene editing raises questions about autonomy and consent. Who has the right to decide which genes are edited and which are not? How does one obtain informed consent for such a complex technology with long-lasting consequences? These are questions that society and policy makers must address.

Finally, Prof. Zhang advocates the inclusion of diverse perspectives in the public debate on gene editing. She argues that epistemic justice, recognition and inclusion of diverse forms of knowledge, are essential for a fair and balanced discussion on gene editing.

Joy Zhang

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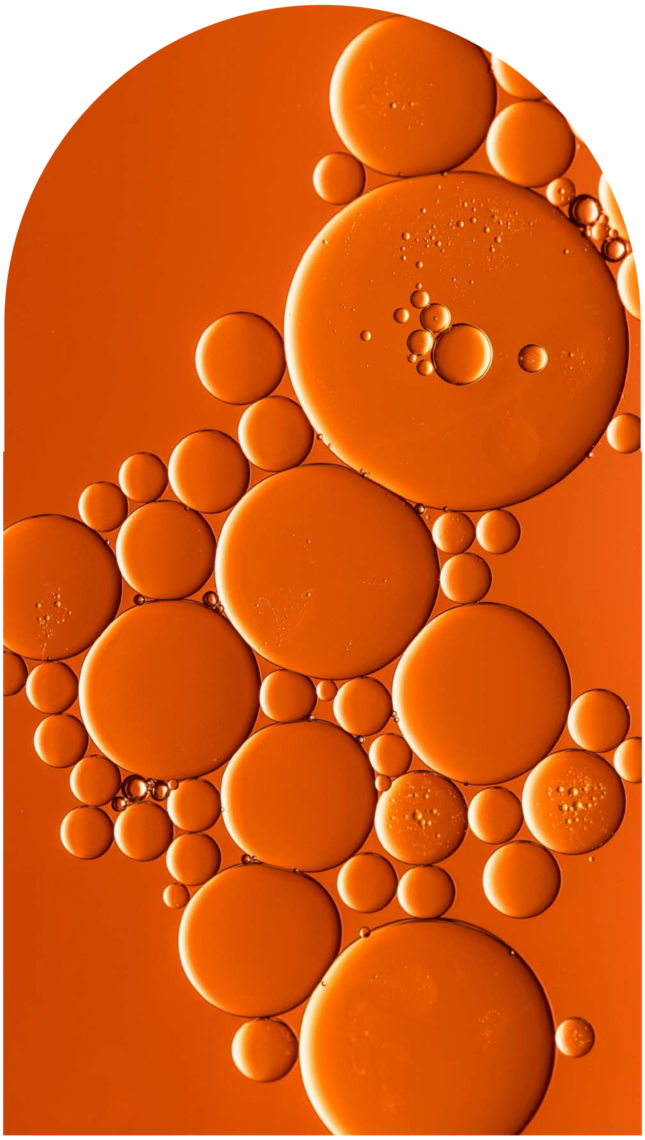
Ethics, philosophy, transhumanism and regulation

3

Ethics, philosophy, transhumanism and regulation

A new narrative



The convergence of neuroscience, neurotechnology, artificial intelligence and biotechnology is bringing about a huge breakthrough for people's health and well-being. But many of the initiatives are still in the very early stages of validation and it will be years before the solutions presented so far are available on a large scale. Effective communication of advances in neuroscience and biotechnology is essential to foster public understanding and acceptance of these disciplines.

It is necessary to communicate these contributions to the general public, knowing how to explain them in clear and accessible terms, conveying the enormous potential possibilities without falling into exaggeration, and unpacking the ethical and legal challenges facing society.

A well-informed society must engage in dialogue to find the best solutions, supporting innovations and social progress, while demanding adequate regulations to safeguard human rights and that the ethical responsibilities of all players involved are fulfilled.

Scott Simon, one of the most admired writers and broadcasters in the United States and a trustee of the Bankinter Innovation Foundation, asks: if between 80 and 130 billion dollars have been spent on the COVID-19 vaccine in the U.S. alone,

Pere Estupinyà y Scott Simon

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why don't similar efforts go into creating vaccines against cancer or diabetes and control these diseases in 6 months or 1 year?

On a different note, when communicating advances, Simon says it is necessary to take into account the different sensitivities and values of the public. For example, there is a part of society that considers that Down syndrome is not a disease but a natural condition and that it brings to people with trisomy 21—another name for the syndrome—a number of human characteristics that are particularly valued. In that case, would we want a world without Down syndrome?

Pere Estupinyà, presenter and director of the program "El Cazador de Cerebros" (The Brain Hunter), believes that to transmit all the advances in human repair and improvement, the first thing to do is to simplify and then create a testimonial story with one absolutely impressive, easily understandable advancement. From there, develop the communication according to the target audience.

From the scientists' side, **Mauro Costa-Mattioli** believes that communicators should team up with scientists to transmit knowledge and perform the necessary educational work. Collaboration between scientists, communicators and educators can facilitate the creation of attractive and educational content that highlights the relevance and impact of these advances in everyday life, thus promoting a better-informed society, one more receptive to scientific innovation.

Transhumanism and the future of humanity

Transhumanism is an intellectual and cultural movement that **promotes the improvement of the human condition, especially through the use of technologies that can enhance the intellectual, physical and psychological capacity of human beings**.

Transhumanism has gained relevance in the context of neurotechnologies and the future potential of humanity. We could define transhumanism as an extension of the classical humanistic project that seeks to improve the human condition. While classical humanists focused on education and the liberal arts to achieve this goal, transhumanists propose that technological advances can also be used to overcome human limitations. This is how Anders Sandberg, a researcher working at the Future of Humanity Institute

Anders Sandberg

Ver vídeo

at Oxford University, has conducted numerous research and published on the topics of cognitive enhancement, the risks of artificial intelligence, brain simulation and the ethics of human enhancement.

Human life, with its short duration and cognitive limitations, can be enhanced through technology. This could open the door to experiencing new feelings, enhancing our mental and physical capabilities, and even transcending what is traditionally considered "human." However, not all transhumanists agree on what constitutes a "good" or "desirable" enhancement, leading to intense debate.

The desire to better and improve oneself is intrinsically human. The Renaissance philosopher Pico della Mirandola, in his work "*Oratio de Hominis Dignitate*," argued that what makes us unique as human beings is our ability to change and improve. This idea is fundamental to transhumanism. Transhumanism focuses not only on individual improvement, but also on how these improvements can benefit society as a whole. For example, vaccines are a form of collective enhancement that has had a positive impact on public health. In addition, many people have already adopted forms of technological enhancement, such as consuming caffeine to increase alertness or using drugs to improve cognitive performance.

From an ethical perspective, transhumanism raises numerous questions. To what extent is it ethical to modify the human body? Should society support and fund these enhancements? How do we balance safety with the desire for enhancement? These are just some of the questions that arise in the transhumanist debate.

As for the future of humanity, transhumanism suggests that **humans can and should use technology to overcome their biological limitations**. This could involve anything from **enhancing our physical and intellectual capabilities, to life extension** and ultimately the possibility of **digital or biological immortality**.

Anders Sandberg groups the fields of action of transhumanism into four major blocks:

- **Cognitive enhancement:** the idea of using drugs, behavior modification techniques or brain-computer interface technologies to improve human cognitive abilities, such as memory, attention and intelligence.
- **Risks of artificial intelligence:** Many transhumanists, including Sandberg, worry about the potential risks of advanced artificial intelligence. This issue refers to the idea that AI could become more intelligent than humans and potentially pose a threat to humanity.
- **Brain simulation:** Sandberg has worked in the field of brain simulation, which is the idea of modeling and simulating brain activity on a computer. This area of research could have implications for the understanding of consciousness and the possibility of "digital life" beyond physics.
- **Ethics of human enhancement:** The idea of enhancing humans through technology raises numerous ethical issues, from the democratization of access to these technologies to the implications of allowing people to modify their own capabilities.

Right to a human decision

AI can be seen as an extension of human enhancement, not only in terms of technological assistance, but also in decision making. In this context, the concept of the "right to a human decision" refers to the idea that individuals should have the right to have **important decisions that affect us made by humans, not by algorithms or AI systems**.

There are several reasons why this concept is important: first, AI algorithms, no matter how advanced, cannot capture the full range of human and emotional factors that may be relevant in decision making. Humans have an intuitive understanding of factors such as **empathy, moral judgment, and social context that machines cannot replicate**. Second, there are issues of responsibility and accountability. When a decision is made by an algorithm, it can be difficult to **determine who is responsible if something goes wrong**. Finally, the right to a human decision is also related to **human dignity**. It can be argued that being judged or evaluated by an algorithm can be dehumanizing.

So explains John Tasioulas, Professor of Ethics and Philosophy of Law at the University of Oxford and Director of the Institute for Ethics in AI. Professor Tasioulas is working to develop ethical and legal frameworks that can address these and other issues related to the growing use of AI in society.

John Tasioulas

Go to profile

In an era dominated by artificial intelligence, it is essential to consider not only what technology can do, but also what it should be allowed to do, always respecting the dignity and fundamental rights of the human being

John Tasioulas

View video

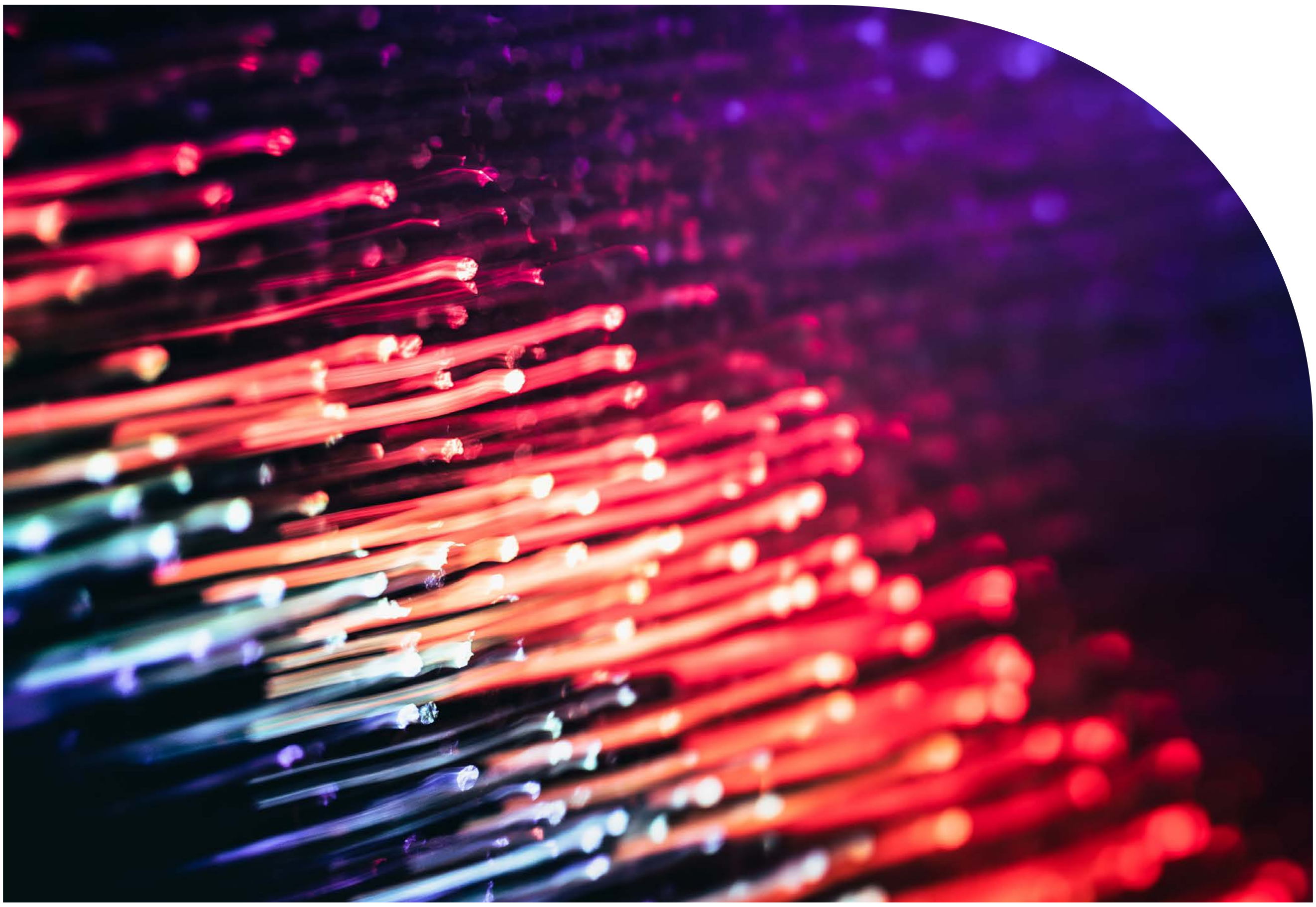
Prof. Tasioulas stresses that beyond the common good, it is essential to consider the concept of collective and individual rights. These rights act as limits to what can be imposed on individuals, even in the name of the common good, underlining the intrinsic dignity and value of the human condition.

The professor emphasizes the **relationship between the human condition and morality**, using the example of the Greek gods, who, despite their power, were not exemplarily moral. Tasioulas suggests that **any attempt to transcend the human condition could erode our basic understanding of morality**.

In the context of emerging technologies, Tasioulas raises the question of whether the current human rights framework, as set out in the Universal Declaration of Human Rights, is still adequate. He proposes three possible modifications: reinterpreting existing rights, considering new right bearers and, finally, the possibility of new rights, such as the right to Internet access or the right to a human decision.

The professor cautions against the hasty assumption that new technologies automatically require a new regulatory framework. Instead, he urges consideration of how existing human rights can address the challenges presented by technology. However, he does not rule out the need for specific additions, citing examples such as Article 22 of the GDPR and the AI Bill of Rights.

Tasioulas lays out the advantages and disadvantages of automated decisions within the concept of the "right to a human decision." While an automated system might offer consistency and efficiency, there are fundamental concerns about the justification and accountability of such decisions. The professor stresses the importance of solidarity and human interaction in the decision-making process, valuing collaboration in the joint pursuit of justice.



To conclude, some key considerations on ethics and regulation of Artificial Intelligence, are:

Diverting attention to the ethics of AI: There is a perception that large companies controlling artificial intelligence may be more interested in discussing ethics than in advancing regulatory processes. Ethics could be used to divert attention away from the need for regulation.

Interpretation of ethics: Ethics should not be viewed simply as a soft, non-enforceable form of regulation. All forms of regulation have an ethical basis, since ethics is concerned with what constitutes a good life and our obligations to others

Legal vs. moral rights for AI: It is crucial to distinguish between legal rights and moral rights when considering granting rights to artificial intelligence entities. While it is possible to grant legal rights to robots to serve human interests, this does not imply that they have underlying moral rights.

Development of artificial general intelligence (AGI): Large technology companies claim that their goal is to develop AGI, suggesting that it will be a powerful tool for solving problems. This perspective may be inconsistent, since, **if AGI has human-like capabilities, it should be considered as a rights-bearer and not simply as a tool.**

Dependence on AI systems and loss of human skills: As we rely more on AI systems to make decisions, there is a risk that **humans will become dependent on these systems and lose essential skills**. In addition, biases may emerge in the systems that humans cannot detect without the help of AI.

Economic growth and deep values: Economic growth, often promoted as a goal of technology policy, may not reflect the deeper values that are important to society. **It is essential to question whether AI development actually improves our lives or simply satisfies market demands.**

AI policy perspective and pathway to reliable AI in Europe -H3

AI can be used to improve neuroscience research and for the creation of advanced algorithms that lead to the design of new drugs, as illustrated throughout this report. In addition, **AI can be seen as a human enhancement that expands our cognitive capabilities**: from tools to help autistic children to applications to detect pain faces in dementia patients.

With so many diverse fields of application for AI, it is essential to take an ethical and human-centered approach to AI development and regulation. At the time of the Future Trends Forum, the **first regulation on artificial intelligence in Europe**, the so-called EU AI Law, was being passed in the European Union.

Isabelle Hupont, scientific officer at the European Commission, has been working in the field of face processing, which refers to AI systems that take facial images or videos as input data and, using AI algorithms, obtain information such as a person's identity, emotions or demographic attributes. Hupont's work focuses on AI in the context of the European Commission's AI Act, which sets out harmonized rules on AI and the 7 requirements for trusted AI defined by the European Commission's High Level Expert Group on AI.

The 7 requirements are:

1. Human agency and supervision;
2. Technical robustness and safety;
3. Privacy and data governance;
4. Transparency;
5. Diversity, non-discrimination and equity;
6. Social and environmental welfare; and
7. Responsibility.

Isabelle Hupont

View video

According to the AI Act, there are **4 levels of risk for AI applications**, ranging from the highest to the lowest:

1.

"**Unacceptable**" risk or prohibited use cases, which cover harmful uses of AI or uses that contradict ethical values.

2.

"**High risk**" use cases, which are identified through a list of "high risk" AI application areas that may have an adverse impact on the safety, health or fundamental rights of individuals.

3.

"**Transparency**" risk use cases, subject to a limited set of transparency rules, e.g., informing people who are exposed to such a system.

4.

"**Minimal risk**" or no-risk use cases, covering all other AI systems that can be developed and used in the EU without additional legal obligations beyond those already in place.

The AI Act has many explicit and implicit references to facial processing. For example, the use of real-time biometric identification systems in publicly accessible spaces for law enforcement purposes is considered a prohibited practice with some exceptions, such as the targeted search for potential victims of crime (including missing children), the prevention of a terrorist attack, or the pursuit of a suspect of a criminal offense.

Neurorights: ethics and neurotechnology; is it time for new human rights?

As noted throughout this report, neurotechnology is advancing by leaps and bounds. This technological revolution raises **fundamental questions about the essence of what it means to be human** and how we protect our privacy, autonomy and identity in the age of neuroscience.

The brain, as the epicenter of our emotions, thoughts and memories, is the organ that defines our identity. The ability to record and alter brain activity not only means that we can better understand how the brain works, but also influence how we think, feel and act. This prospect, which is fascinating from a medical and scientific point of view, also raises significant ethical and moral concerns.

Neurorights emerge as a response to these concerns. These rights seek to **ensure that people are protected from abuse and exploitation in the age of advanced neurotechnology**. The idea is that, just as we have rights that protect our freedom of expression, privacy and security, we should also have rights that protect our minds.

Rafael Yuste, Director of the Center for Neurotechnology and Professor of Biology at Columbia University, President of the NeuroRights Foundation, and a pioneer in the field, has been a key player in promoting the idea that **we urgently need a human rights framework that specifically addresses the implications of neurotechnology**. Neurotechnology, Prof. Yuste explains, is understood as methods, tools or devices that have two main purposes: to record the activity of the nervous system (either central or peripheral) or to modify that activity. These devices can be electrical, electronic, optical, magnetic, acoustic, nanotechnological or chemical, and are now combined with artificial intelligence and deep neural networks. According to Prof. Yuste, there are two types of devices worth pointing to when dealing with neurorights: those that require surgery to be implanted and non-surgical devices, such as wearables. Neurotechnology is essential because the brain, which generates all our mental and cognitive abilities, is the organ that defines our essence as human beings. This technology could allow us to understand how the brain works and how our minds are generated, which would be a significant development in neuroscience. In addition, neurotechnology is crucial to address mental and neurological diseases, which currently have no cure due to our lack of understanding of the brain.

Neuro-rights... why now?

Given the enormous potential of neurotechnology, Rafael Yuste devised and succeeded in getting the BRAIN initiative underway in the USA. This is a 15-year-long initiative and involves more than 550 laboratories. In 2023 alone, it has received $900 million in funding and is beginning to generate many of the tools mentioned above, especially tools for use in humans. The US BRAIN initiative has been followed by similar initiatives in other countries, including China, whose brain initiative is supposed to be three times the size of the Americans' and is led by the military with the goal of merging neurotechnology with AI. There are initiatives in Japan, South Korea, Australia, Canada, Israel and, along with the U.S. BRAIN initiative, Europe launched Project Human Brain, which ends this year. Its focus is a bit different, as it doesn't really focus on the technology, but rather on the data generated by the technology. It complements the rest beautifully. All these brain initiatives around the world decided to come together in an international initiative. Although it is currently loosely coordinated, it represents a global effort to develop neurotechnology.

Private industry has not been left on the sidelines. In fact, it is estimated that, as of 2022, private investment in neurotechnology in the U.S. exceeds the BRAIN initiative by a factor of six.

With all these initiatives underway, neurotechnology is enabling highly advanced research in both animals and humans. In animal studies, such as mice, cutting-edge techniques such as holographic optogenetics are used to measure and manipulate brain activity precisely at the level of individual cells. One example is a study where an image could be implanted into the visual cortex of a mouse, causing the mouse to act as if it had seen that image. This experiment has been replicated by laboratories in the US and the UK. In addition, MIT and other groups have implanted false memories in the hippocampus of mice.

For humans, neurotechnology has enabled advances such as brain-computer interfaces that help paralyzed patients to move or communicate. Recently, thanks to artificial intelligence, non-invasive techniques have been developed to decode brain activity. For example, studies have been published in Japan, Singapore and the University of Texas at Austin that use fMRI to decode images and language. Facebook is also working on devices that can decode speech using EEG (electroencephalograms) and MEG (magnetoencephalograms). In addition, a Boston University study has shown that transmagnetic stimulation can improve memory.

The need to define neuro-rights and include them in legislation is becoming urgent, says Prof. Yuste, not only because of all the above, but also because the next great technological revolution could be to replace smartphones with devices that would allow us to connect directly to the network using some kind of brain-computer interface. And also, because neurotechnology could have military applications.

The neuro-rights proposal

In 2017, a group of experts including Prof. Yuste, known as the Morningside group, met at Columbia University to discuss these implications. They concluded that neurotechnology raises human rights issues. Since then, Prof. Yuste's work with the NeuroRights Foundation has led to the proposal of four specific rights that address key areas of concern.

These rights are not only theoretical. There are already concrete examples of how neurotechnology can influence our identity and autonomy. Deep brain stimulation, for example, has shown changes in the personality of some patients. While this technique has medical benefits, it also raises questions about who we are and how external interventions can change that.

Prof. Yuste advocates the inclusion of **neuro-rights** in the Universal Declaration of Human Rights, adopted by the United Nations, since, for this expert, the ethical and social consequences of neurotechnology are a human rights issue.

The four specific rights proposed by Yuste and the group of scientists and ethicists he works with are:

- **Right to mental identity:** To your own mental identity, in other words, to yourself, to your consciousness. There are already studies with patients who, after deep brain stimulation for Parkinson's disease, report alterations in personality. Our identity, our consciousness, is also generated by our brain. Therefore, if we can stimulate the brain, we can manipulate that as well.

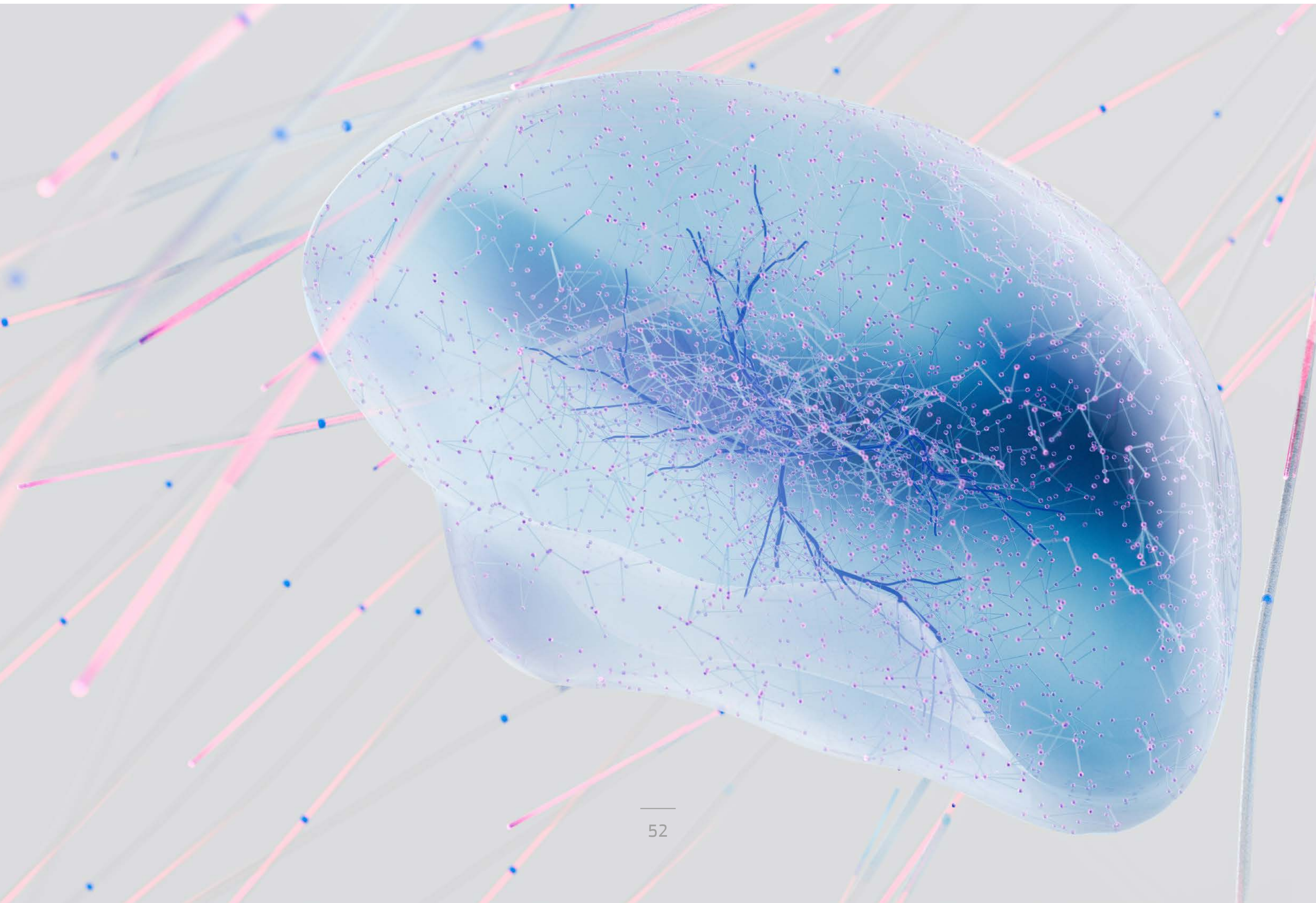
- **Right to free will:** essentially our cognitive freedom to act in a manner undisturbed by the external use of neurotechnology.

- **Right to mental privacy:** that is, the right to not have your brain activity decoded without your consent.

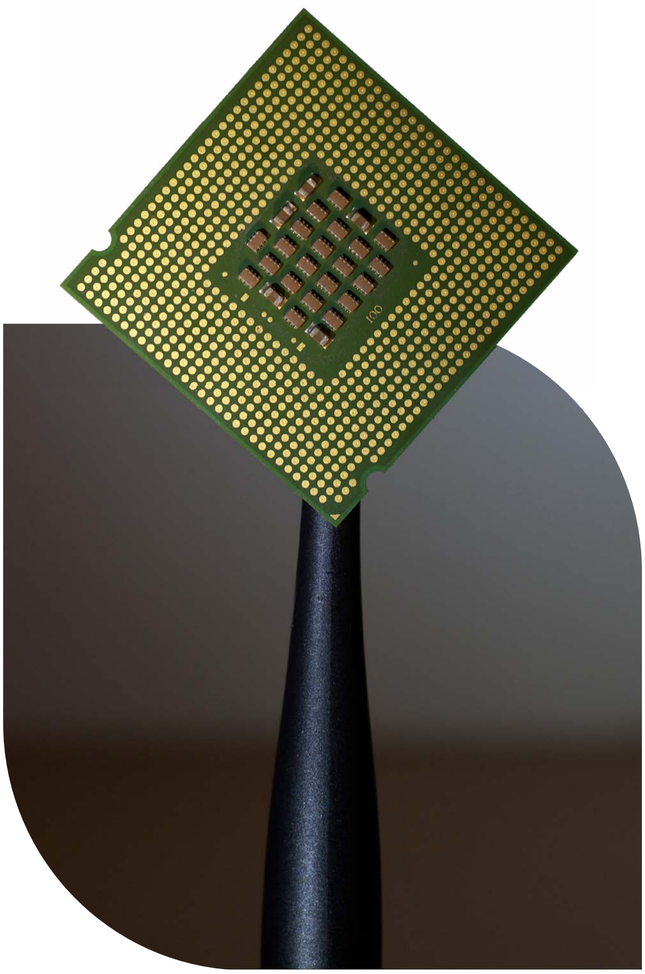
- **Right to equal access to advances in brain enhancement:** mental enhancement seems inevitable. It should be introduced into society under the universal principle of justice, to avoid two types of humans: a superspecies with mentally enhanced hybrid humans and another species that is not mentally enhanced.

The right to free will and the right to mental privacy are essential in a world where corporations and governments could have the ability to "read" or influence our thoughts.

Furthermore, the right of equal access to brain enhancements is crucial to ensure that we do not create a society divided between those who can afford neurotechnological enhancements and those who cannot. This division could lead to significant inequalities in terms of cognitive abilities, opportunities and quality of life. Prof.



Yuste illustrates the importance and relevance of this right in light of Neuralink's recent announcement that it has obtained US FDA approval to begin human trials of its implantable chip, Neuralink's stated goal being to **increase human mental capacity by incorporating artificial intelligence into our brain processes using neurotechnology**.



The NeuroRights Foundation is not only proposing these rights, but also actively working to have them recognized and adopted worldwide. Its work with governments and international organizations is a crucial step in ensuring that neurotechnology is developed in an ethical and responsible manner. Experts led by Yuste in the NeuroRights Foundation have conducted a gap analysis comparing these four neurorights with existing human rights regulations around the world. The conclusion is that the current human rights system is not prepared to face this challenge.

As examples of the actions being carried out by NeuroRights, Prof. Yuste points out the following:

- In Chile, they are advising the senate on a constitutional amendment to protect brain activity and the information that comes from it as a basic constitutional right.
- The United Kingdom is also an example of anticipation in the regulation of neurotechnology applications with the report produced by the Regulatory Horizons Council (RHC).
- They also advise the United Nations and the European Union on the design of new neurotechnology regulations. Specifically, in Spain, the recommendations of the NeuroRights Foundation have been taken into account in the Charter of Digital Rights.

The documentary "The Theater of Thought", made in collaboration with renowned filmmaker Werner Herzog, is an outreach effort that seeks to raise public awareness of these issues. Although not yet available to the general public, it promises to offer a deep and thoughtful look into the future of neurotechnology and the need to protect our brain rights.

4

Glossary

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Bb

Bioelectricity

any electrical phenomenon that is actively generated by cells or that is applied to cells to affect cell phenotype. Electrical phenomenon means any biological-cell function or activity that depends on either the separation of charge (voltage), or the movement of ions (current), generally through channels or by pumps.

Biohacking

a combination of actions by diverse techniques and tools with the purpose of optimizing our mind and life to reach a total control of our biology. Biohacker means to be the best version of oneself.

Biomachines

is part of biophysics. Biomechanics deals with the movement processes in biological systems as well as the functions of biological movement apparatuses. The use of robots in this field can help researchers better understand how vertebrate locomotion evolved over time.

Biomarker

substance that is used to indicate a type of biological statement. It may be measured objectively and valued as an indicator of a normal biological process, pathogenic statement or as a response to a pharmacologic treatment.

Bionic Prosthetic

technology used to replace a missing body part which may have been lost due to trauma, disease, or congenital defect.

Biotechnology

is a combination of techniques where alive cells, tissue culture and molecules derived from organisms are used to obtain and modify a product or to develop a microorganism to use it with a specific purpose.

Brain-Machine Interface (BMI)

a communication pathway that allows direct interaction between the brain and external devices or machines. BMIs enable individuals to control external devices or receive sensory feedback through neural signals, with applications in prosthetics, assistive technology, and neurorehabilitation.

Brain Organoids

three-dimensional cultures of brain tissue derived from human pluripotent stem cells or other cell sources. Brain organoids can mimic certain aspects of brain development and function, providing a model for studying neurodevelopmental disorders and drug testing.

Cc

Cognition

the cognition function are the mental processes which allow us to receive, process and elaborate information. Is a learning method to assimilate the data which reach the human being by different ways: perception, experiences, and general convictions in order to turn them into knowledge.

Cognitive Enhancement

refers to the use of various techniques and interventions aimed at improving and optimizing cognitive functions, such as memory, attention, problem-solving, and learning. It involves the application of strategies and technologies to enhance human cognitive abilities beyond their natural capacity.

CRISPR

a gene editing technology that allows scientists to make precise modifications to the DNA of living organisms. It is based on a naturally occurring defense mechanism found in bacteria, where certain segments of their DNA contain repetitive sequences interspersed with unique sequences derived from viral genetic material.

Cybernetics

the study of communication and control processes in living organisms and machines. It involves the interaction between humans and technology, particularly in relation to feedback mechanisms and self-regulation.

Dd

Deep Brain Stimulation (DBS)

a neurosurgical procedure that involves the implantation of a medical device called a neurostimulator in the brain to alleviate the symptoms of certain neurological conditions. DBS works by delivering electrical impulses to specific areas of the brain through electrodes, which are connected to the neurostimulator.

Digital Neurotherapeutics

delivering evidence-based therapeutic interventions to patients that are driven by software to prevent, manage or treat a medical disorder or disease. They are used independently or in concert with medications, devices, or other therapies to optimize patient care and health outcomes.

Diverse intelligence

an emergent field of study in which we learn to recognize, communicate with, manipulate, and ethically relate to agents in unconventional embodiments. This means, problem-solving, learning, and memory capacity in systems like slime molds, single cells, molecular networks, organs, and synthetic or bioengineered organisms. The intelligence is deployed in problem spaces such as physiological, anatomical, and of course the familiar 3-dimensional world of conventional "behavior".

Ee

Electronics Simulation

mathematical models that replicate the behavior of an actual electronic device or circuit. Electronics simulation software engages its users by integrating them into the learning experience.

Epigenetics

the study of heritable changes in gene expression or cellular phenotype that do not involve changes to the underlying DNA sequence. Epigenetic modifications can be influenced by environmental factors and have implications for human health and development.

Exoskeletons

mechanical structures or wearable devices that are used as support and assistance to the human movements or to enhance the human capabilities.

Gg

Gene Editing

alteration of the genetic material of a living organism by inserting, replacing or deleting a DNA sequence, typically with the aim of improving some characteristic of a crop or farm animal or correcting a genetic disorder.

Genetic Engineering

process that uses laboratory-based technologies to alter the DNA makeup of an organism.

Genetic Enhancement

application of biological, economical, and mathematical principles to increase the productivity, the resistance to the environment and sicknesses in order of reach a better adaptation of the environment.

Genetic Modification

The deliberate alteration of an organism's genetic material using biotechnological techniques, such as gene editing or genetic engineering, to introduce new traits or characteristics.

Graphene Nanotechnology

two-dimensional carbon allotrope material with potential mechanical properties for the use of medicine as a therapeutic and diagnosis tool. One of the most promising nanomaterials due to its electrical properties: optical transparency, high current-carrying capability and high carrier mobility or velocity.

Hh

High Intensity Focused Ultrasound (HIFU)

a therapeutic procedure used in medicine. It uses non-invasive focused ultrasound energy to heat and destroy targeted tissue. This technology can be guided by MRI (Magnetic Resonance Imaging) or ultrasound imaging to precisely target the area of interest.

Human-Machine Interface (HMI)

The point of interaction or communication between humans and machines. HMIs can include physical interfaces, such as touchscreens or keyboards, as well as virtual interfaces, such as voice recognition or gesture control.

Mm

Magnetic Simulation

artificial magnetic field that is designed to mimic how real compounds would respond to each other’s magnetic properties. The simulation can analyze a permanent magnet, or a magnetic field made by a flow of current.

Metacognition

refers to the process of thinking about one's own thinking. It involves being aware of and actively monitoring our thoughts, knowledge, and cognitive processes. Metacognition allows individuals to reflect on their own mental states, evaluate their understanding and performance, and make adjustments accordingly.

Molecular Electronics

the study and application of nano building blocks for the fabrication of electronic components. Molecular scale and material are two subdivisions of molecular electronics used in high-tech and artificial intelligence devices.

Nn

Nanomedicine

the application of the nanotechnology in the biomedicine to enhance the human life quality combating diseases in an innovative way.

Nanotechnology

type of technology which main object is to design and manipulate the material in an atom and molecular level with medical and industrial purposes.

Neuroelectric

is a non-invasive and high-definition electrical brain stimulation technology for personalized neuromodulation. By measuring and modifying brain function, the aim is to restore brain health, minimize disabilities and create a better life for patients.

Neuroengineering

discipline that uses techniques to comprehend, repair, replace and enhance the sicknesses of the neuronal systems.

Neuromodulation

therapy used to intervene in the peripheral and central functioning of the nervous system. It is an invasive technique.

Neuronal Implants

technology devices which are connected to a human brain. They are located in the brain surface. They act like biomedical prosthesis in dysfunctional brain areas.

Neural Stem Cells

undifferentiated cells found in the central nervous system that have the potential to differentiate into various types of neurons and glial cells. Neural stem cells hold promise for regenerative medicine and repairing damaged neural tissue.

Neurodiversity

the concept that neurological differences, such as autism or ADHD, should be recognized and respected as natural variations of human neurology, promoting acceptance and understanding rather than viewing them as deficits to be fixed or enhanced.

Neuroethics

the field of ethics that examines the ethical implications of neuroscience and neurotechnology, particularly in relation to brain enhancement, privacy, and informed consent.

Neurodegenerative Disorders

a group of conditions characterized by the progressive degeneration and dysfunction of neurons in the brain or peripheral nervous system. Examples include Alzheimer's disease, Parkinson's disease, and amyotrophic lateral sclerosis (ALS).

Neuroimaging

techniques for visualizing and mapping brain structure and function. This includes methods such as magnetic resonance imaging (MRI), positron emission tomography (PET), and functional magnetic resonance imaging (fMRI).

Neuropharmaceuticals

is the study of how drugs can affect the cellular functioning in the nervous system.

Neuroplasticity

the brain's ability to reorganize its structure, function, and connections in response to learning, experience, or injury. Neuroplasticity is a fundamental mechanism underlying learning, memory, and recovery from brain damage.

Neuroprosthetics

the development and use of artificial devices or systems that replace or enhance the function of the nervous system, such as brain-computer interfaces or prosthetic limbs controlled by neural signals.

Neurorights

refers to the concept of ethically and responsibly applying neuroscientific knowledge and advancements for the betterment of individuals and society as a whole. It encompasses the idea of utilizing neuroscience in a manner that respects and upholds fundamental human rights, privacy, autonomy, and consent.

Neurotechnology

technology to understand the brain, visualize its processes and control, repair or enhance its functions. The neurotechnology employs diverse techniques to register brain activity and stimulate some parts of it. We can make differences between invasive techniques and non-invasive techniques.

Oo

Optogenetics

a technique that uses light-sensitive proteins to control and manipulate the activity of specific neurons in living tissue. Optogenetics allows for precise control of neural activity and has applications in neuroscience research and potential therapeutic interventions.

Pp

Physical Enhancement

refers to the utilization of various methods, interventions, and technologies to improve and augment human physical capabilities beyond their natural state.

Ss

Sensory Devices

are electronic instruments or systems designed to detect and measure various physical phenomena in the surrounding environment. These devices are engineered to mimic or enhance human sensory capabilities, allowing us to perceive and interpret information that would otherwise be inaccessible to our natural senses.

Sensory Enhancement

refers to the augmentation or amplification of human sensory capabilities beyond their natural limits. It involves the use of technological interventions, such as wearable devices or implants, to enhance one or more of the five senses: sight, hearing, taste, smell, and touch.

Stimulation Therapies

the fact of activating or inhibiting the brain directly with electricity. The electricity can be given directly by electrodes implanted in the brain, or non-invasively through electrodes placed on the scalp.

Synthetic Neurobiology

a field that combines synthetic biology with neuroscience to engineer novel biological systems or devices for understanding and manipulating neural circuits. It involves the design and construction of genetically-encoded tools to probe and control brain function.

Tt

Transhumanism

is a philosophical and intellectual movement that advocates for the enhancement of human capabilities through the integration of advanced technologies and scientific progress. At its core, transhumanism seeks to overcome the limitations of the human condition, such as aging, disease, and cognitive limitations, by utilizing emerging technologies like genetic engineering, nanotechnology, artificial intelligence, and cybernetics.

Xx

Xenobot

a synthetic living machine, or proto-organism, made of frog skin cells. One example of a new technology with which we can explore the possibility space of un-edited genomes.

Gratefulness

Our thanks to all the members of the Future Trends Forum (FTF) who attended the meeting, and to the collaborators in the organization of the meeting:

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The views expressed in this report are those of the author and do not reflect the opinion of the experts who participated in the Future Trends Forum meeting.

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