TECH REPORT: BRAIN-COMPUTER INTERFACES (BCI)

IDB

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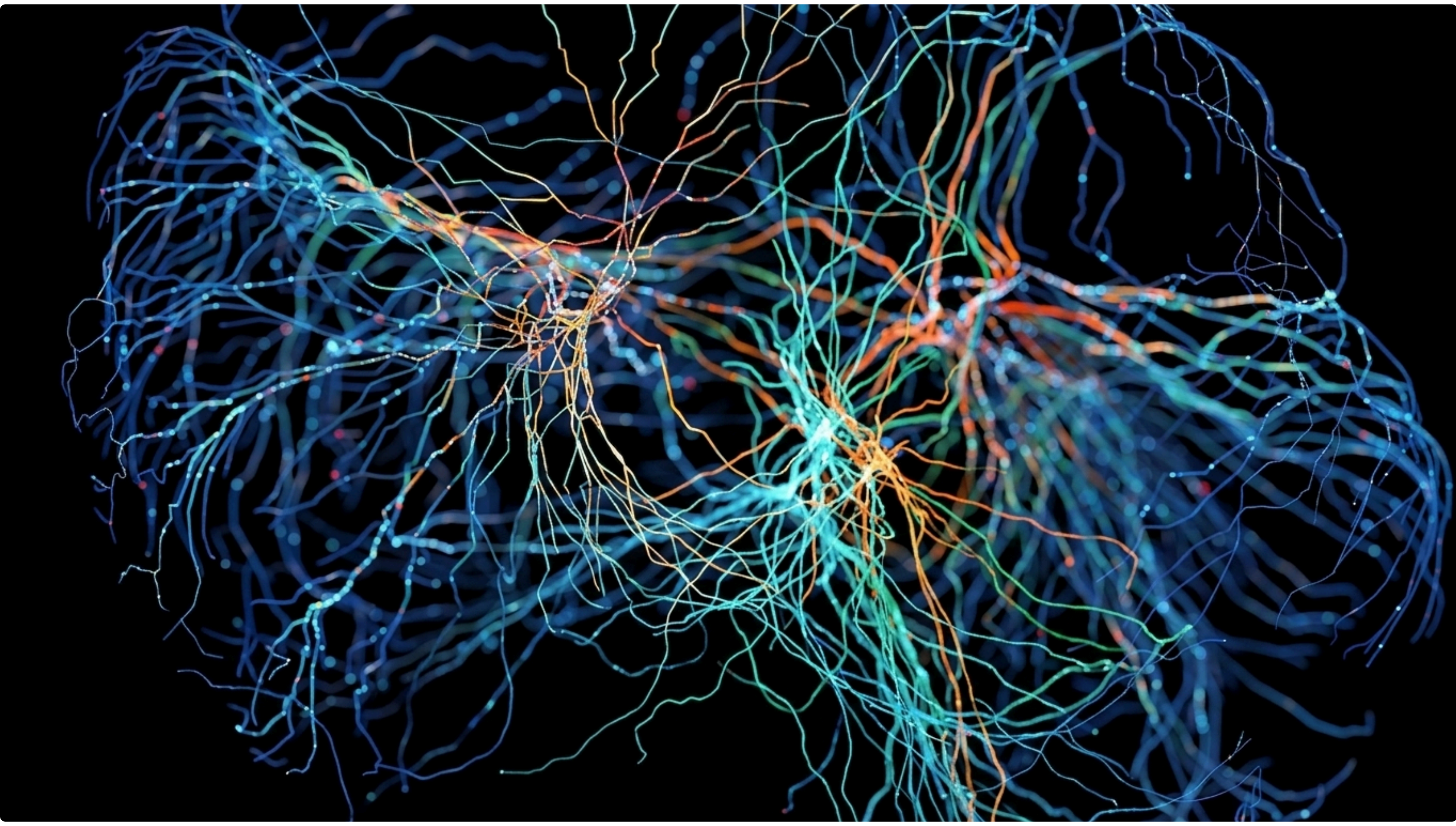

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EXECUTIVE SUMMARY

Brain-Computer Interfaces (BCIs) represent one of the most advanced frontiers of contemporary technological innovation, enabling a direct connection between brain activity and digital devices. This technology, resulting from the convergence of neuroscience, Artificial Intelligence (AI), biomedical engineering, and data science, allows neural signals to be translated into operational commands, opening new possibilities in human-machine interaction.

This report analyzes the current state of BCIs, their development trends, and their implications from a development-oriented perspective, with special focus on Latin America and the Caribbean. Throughout the document, we examine the technological foundations of these interfaces, their evolution – from research environments to emerging clinical applications - and the global innovation ecosystem driving their advancement.

In technological terms, BCIs have evolved from experimental systems based on electroencephalography toward more sophisticated solutions that integrate machine learning algorithms, high-precision implantable devices, and closed-loop stimulation systems. These innovations have enabled progress in concrete applications, particularly in the health sector, where BCIs are used to restore motor functions, facilitate communication in people with paralysis, and develop new therapeutic strategies in neurology and psychiatry.

The report also highlights the potential impact of BCIs beyond the health sector. In the medium and long term, these technologies could transform areas such as productivity, education, interaction with digital systems, and collaboration with AI. However, many of these applications are still in early development stages, which implies a high degree of uncertainty regarding their adoption trajectories.

The analysis of the global ecosystem shows a strong concentration of capabilities in developed countries, particularly in the United States, China, and European Union countries, where public investment, academic research, and business development converge. Technology companies, leading universities, and research centers drive significant advances, while the global BCI market presents projections of sustained growth in the coming years.

From the perspective of Latin America and the Caribbean, the report identifies opportunities and challenges. On one hand, the region could benefit from BCI adoption in priority areas such as neurological rehabilitation, inclusion of people with disabilities, and strengthening of health systems. On the other, it faces limitations in terms of scientific capabilities, financing, infrastructure, and regulatory frameworks, which condition its participation in this field.

Likewise, the report addresses the main risks and challenges associated with BCIs, including the protection of neural data, cybersecurity, regulation of medical devices, equity in access, and ethical implications related to autonomy and mental privacy. In this regard, the advances of international organizations in defining principles for responsible innovation in neurotechnology are highlighted.

Finally, the report examines the public policy implications for the region, emphasizing the need to strengthen research and development, adapt regulatory frameworks, promote innovation ecosystems, and advance international cooperation schemes. In this process, the role of multilateral actors such as the Inter-American Development Bank is central to articulating efforts, mobilizing resources, and supporting countries in capacity building.

Overall, the document proposes that BCIs not only constitute an emerging technology but a key component of ongoing transformations in the relationship between humans and the digital world. For Latin America and the Caribbean, understanding these dynamics and anticipating their implications will be fundamental to orienting their development in an inclusive, sustainable manner aligned with the region's priorities.

02

WHAT ARE BRAIN-COMPUTER INTERFACES?

DEFINITION OF BCI

Brain-Computer Interfaces (BCIs) constitute one of the most advanced areas of contemporary neurotechnology. In general terms, we refer to BCIs as systems that establish a direct communication pathway between human brain activity and external devices, allowing neural signals to be translated into digital or physical actions.

More precisely and adopting UNESCO's definition, a BCI is a technology that facilitates direct communication between the human brain and external devices through the interpretation of neural signals, allowing users to control computers, prostheses, or other systems using only their brain activity. This capability opens the possibility of interacting with machines for those who cannot resort to traditional channels of human communication, such as muscular movement or speech.

> *A technology that facilitates direct communication between the human brain and external devices through the interpretation of neural signals.*
>
> — UNESCO

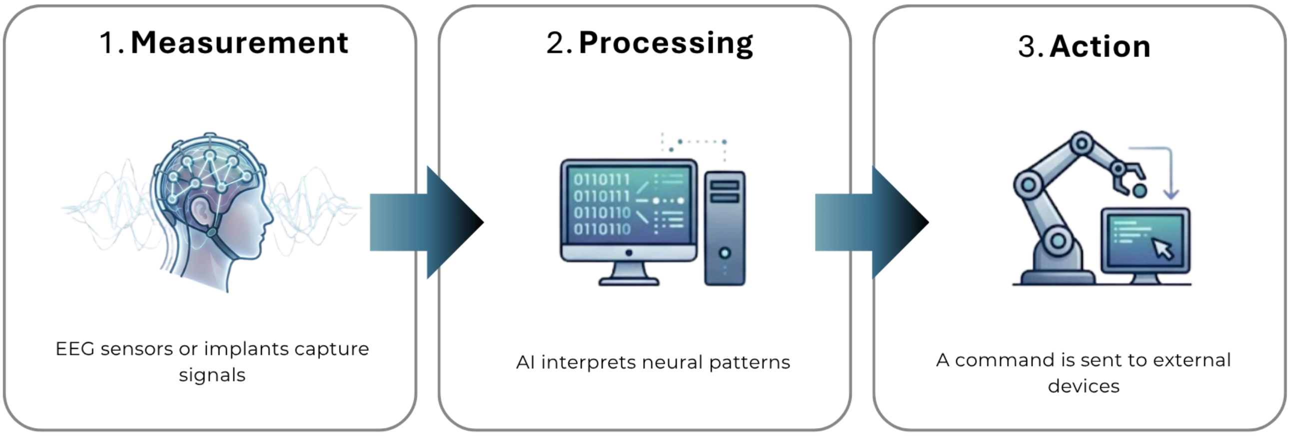
In a more technical sense, Microsoft's definition describes BCIs as systems that measure central nervous system activity and transform it into an artificial output capable of replacing, restoring, enhancing, or complementing the brain's natural functions. This process modifies the interaction between the brain and its environment, enabling new forms of communication and control.

Centrally, all definitions agree on three fundamental elements when defining BCIs. First, they are based on measuring brain activity. Second, they use computational systems to interpret and decode neural signals. Third, they transform that information into functional actions in the digital or physical world, such as moving a cursor, controlling a prosthesis, or interacting with electronic devices.

Although the concept may seem recent, research in brain-computer interface technology dates back several decades. However, recent advances in AI, neural sensors, and data processing have significantly accelerated the development of this technology, bringing it closer to areas such as clinical and commercial applications, which were previously considered experimental.

HOW THEY WORK

The functioning of a BCI can be understood as a chain of processes that connect neuronal activity with the execution of an external action. In simplified terms, the system consists of three main stages: capture of neural signals, data processing, and translation into digital commands.



(AI-generated images)

1. Capture of Neural Signals

The first step consists of recording the electrical or magnetic activity of the brain. This is done through specialized sensors, generally electrodes, capable of detecting small voltage variations produced by neuron activity. Depending on the type of BCI, these sensors can be placed on the scalp, inserted on the brain surface, or implanted directly in brain tissue.

The most commonly used techniques include electroencephalography (EEG), which measures electrical activity from outside the skull, as well as other recording methods that allow for obtaining higher resolution signals when sensors are closer to neurons.

2. Processing through Artificial Intelligence

Neural signals captured by sensors are usually complex, noisy, and highly variable among individuals. For this reason, BCI systems require advanced algorithms capable of identifying significant patterns within large volumes of data. This is where machine learning and AI techniques intervene, analyzing signals to recognize correlations between certain neural patterns and user intentions, such as imagining a movement or focusing attention on a specific stimulus.

The system training process is key. As the user interacts with the interface, the algorithm continuously learns to interpret their neural signals with greater precision, progressively improving the speed and reliability of the generated communication.

3. Translation to Digital Commands

Once relevant neural patterns are identified, the system converts them into commands that can be interpreted by computers or electronic devices. In this way, a brain signal can be translated into actions such as moving a cursor on a screen, selecting letters on a virtual keyboard, activating a robotic prosthesis, or controlling environmental devices.

Together, these three components—capture of neural signals, processing through AI, and translation to digital commands—constitute the technological core of any BCI system.

Brain-computer interfaces can be classified according to the degree of medical intervention necessary to record brain activity. This distinction is important because it implies different levels of precision, clinical risks, and potential applications.

Types of BCI

Non-invasive BCI

- Non-invasive BCIs record brain activity without the need to perform surgery.
- In these systems, sensors are placed on the scalp through devices similar to helmets or bands equipped with electrodes.
- In this type of BCI interface, the most commonly used technique to access brain signals are through EEGs.
- The main advantage of non-invasive BCIs is their safety and ease of use, making them a suitable option for experimental applications, academic research, and some commercial products.
- However, the signals obtained are usually weaker and less precise than other interventions, as they must pass through the skull before being recorded.

Minimally invasive BC

- Between both extremes we can find intermediate solutions known as minimally invasive BCIs.
- n these interventions, sensors are placed near the brain, for example, on the cortical surface or within cerebral blood vessels, through procedures less invasive than open surgery.
- These alternatives seek to combine better signal quality with lower clinical risks, which could facilitate their adoption in broader medical applications in the future.

Invasive BCI

- Invasive BCIs involve the implantation of electrodes directly in the brain through surgical procedures.
- By recording neural signals in close proximity to neurons, these interfaces offer much higher resolution, allowing more precise decoding of the user's motor or cognitive intentions.
- However, this level of precision entails greater medical risks, including possible infections, inflammation, or neuronal damage.
- For this reason, invasive BCIs are mainly used in clinical trials and medical applications, especially in patients with severe paralysis or other neurological conditions.

INTERACTION MODALITIES

In addition to their medical classification, BCIs can also be distinguished according to the way they interact with the user's brain activity.

Passive BCI

- Passive interfaces are centrally used to monitor cognitive or emotional states.
- Instead of actively controlling a device, the system analyzes brain signals related to factors such as attention, stress, or cognitive load.
- This type of application can be used, for example, to assess concentration during complex tasks or adapt digital interfaces to the user's mental state.

Interactive BCI

- Interactive BCIs allow the user to control devices through direct interpretation of neural signals.
- In these systems, the individual voluntarily generates brain activity patterns, for example, imagining hand movement, which the algorithm interprets as specific commands.
- Among the most commonly used mechanisms are decoding of imagined movements from the motor cortex, detection of visual or auditory attention, and event-related potentials, such as the P300 signal (a cognitive evoked potential or positive EEG wave that occurs approximately 300 milliseconds after a significant stimulus).

Active BCI

- Active interfaces combine the previous capabilities and additionally incorporate targeted brain stimulation.
- This means that the system not only interprets neuronal activity but can also modify it through electrical or sensory stimuli.
- This approach is particularly relevant in therapeutic applications, such as neurological treatments based on adaptive brain stimulation.

STATE OF TECHNOLOGICAL MATURITY

Although BCIs have been the subject of research for more than half a century, their development is still in a transition phase between the laboratory and practical implementation. Currently, the technological ecosystem can be understood at three levels of maturity.

Currently, the technological ecosystem can be understood at three levels of maturity.

- **Research Prototypes**: A large part of existing BCIs continues to be developed in academic or research environments. These prototypes allow for developing and testing new methods of neural recording, decoding algorithms, or biocompatible materials. At this stage, the main objective is to validate scientific concepts and improve technological performance.
- **Clinical Trials**: A second level of BCI maturity corresponds to systems that are in clinical testing phases with patients. These trials seek to evaluate the safety, efficacy, and therapeutic viability of BCIs in real medical contexts, such as motor rehabilitation, assisted communication, or treatment of neurological disorders.
- **Emerging Commercial Applications**: Finally, BCIs have begun to be launched as commercial applications, especially in the field of non-invasive devices oriented toward wellness, productivity, or cognitive training. While these solutions still present limited capabilities compared to advanced clinical systems, they reflect the beginning of an emerging market in the field of neurotechnology.

The development of BCIs is in a stage of rapid evolution, driven by advances in AI, materials science, and medical technologies. As these disciplines continue to converge, it is likely that BCIs will progressively move from experimental applications to widely used tools in medicine, rehabilitation, and new forms of human-machine interaction.

03

THE GROWING IMPORTANCE OF BRAIN-COMPUTER INTERFACES

BCIs are consolidating as an emerging technology with the potential to redefine the relationship between humans and digital systems. In a context marked by AI expansion, digitalization of health systems, and development of new forms of human-machine interaction, BCIs represent a significant advance by allowing direct interpretation of neural signals to interact with external devices.

> BCIs are consolidating as an emerging technology with the potential to redefine the relationship between humans and digital systems.

Beyond their technological dimension, this field raises relevant implications for health, social inclusion, productivity, and scientific innovation, which explains the growing interest it generates in the scientific community, international organizations, the private sector, and policy makers.

TECHNOLOGICAL CONVERGENCE

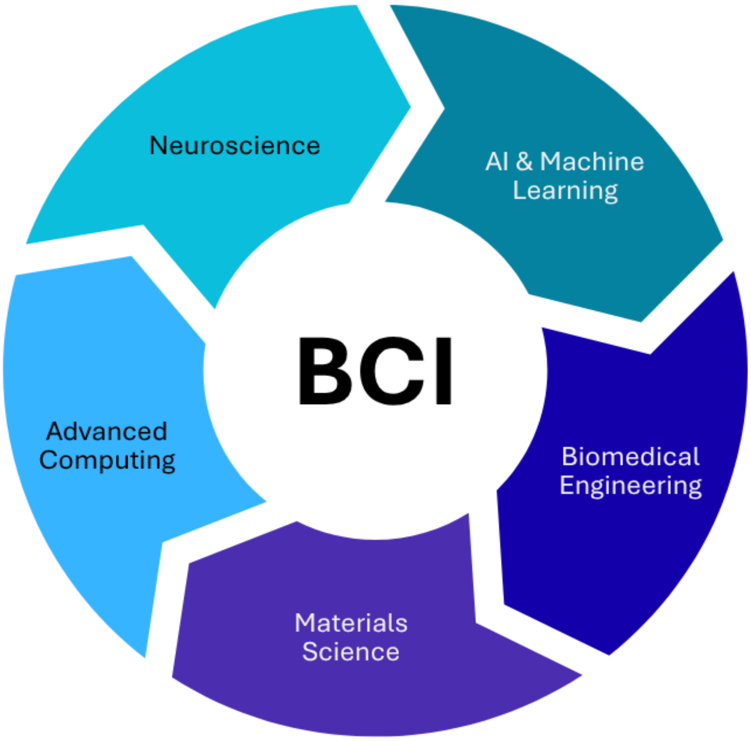
The recent advance of BCIs is the result of convergence between multiple scientific and technological disciplines that, until a few years ago, evolved independently. Among the most relevant are neuroscience, biomedical engineering, AI, materials science, and advanced computing.

First, progress in neuroscience has allowed more precise identification of brain activity patterns associated with motor, cognitive, and sensory functions. This knowledge is fundamental for designing systems capable of recording relevant neural signals and using them as an information source for digital interfaces.

Second, the development of neural sensors and biocompatible materials has significantly expanded the possibilities of recording brain activity safely and with higher resolution. Advances in microelectronics, nanotechnology, and flexible materials have enabled the design of increasingly smaller devices adaptable to biological tissue, facilitating their use in long-term clinical applications.

Added to these advances is progress in AI and machine learning, which have transformed the capacity to interpret large volumes of neural data. Modern machine learning algorithms allow identifying patterns within this data and associating them with specific intentions or actions, improving the precision and speed of interfaces.

Finally, the increase in computational processing capacity and expansion of cloud computing infrastructures have enabled the integration of these different components into systems capable of operating in near real-time. This technological convergence has driven a qualitative change in the field of BCIs, progressively bringing them closer to practical applications in areas such as medicine, neurological rehabilitation, and human-machine interaction.



BCI technological convergence

HISTORICAL EVOLUTION: FROM EXPERIMENTAL RESEARCH TO CLINICAL APPLICATION

The research that gave rise to brain-computer interfaces dates back to the first neurophysiology studies of the 20th century. The development of electroencephalography by German neurologist Hans Berger in 1924 allowed recording human brain electrical activity for the first time, opening a new field for the study of neural signals. For decades, these techniques were mainly used for diagnostic purposes and basic research. It was not until the 1970s when researcher Jacques Vidal, from the University of California, Los Angeles, formally proposed the possibility of using these signals to establish direct communication between the brain and computers, introducing the concept of BCIs. Since then, the field has evolved from laboratory experiments toward increasingly sophisticated clinical and technological applications.

1924

Hans Berger develops EEG

1970s

Jacques Vidal proposes the BCI concept

1990s

First operational systems

2000s

Advances in ML algorithms

2020

Clinical trials in humans

2024

First Neuralink implantation

TODAY

Transition to commercial applications

Starting in the 1990s, the development of new signal processing techniques and the advance of digital computing opened the possibility of using these signals to control external devices. Researchers began to demonstrate that it was possible to move a cursor on a screen or activate simple mechanisms through brain activity patterns, which laid the foundations for the first operational brain-computer interfaces.

The technological progress of the last two decades has significantly accelerated this field. The combination of more sophisticated neural sensors, advanced decoding algorithms, and new implantable materials has allowed advancement from experimental prototypes toward clinical trials in humans, especially in the field of neurorehabilitation. In these studies, patients with paralysis or neurodegenerative diseases have managed to control digital devices or robotic prostheses through neural signals, demonstrating the therapeutic potential of these technologies.

This transition process from the laboratory toward clinical applications represents a turning point for the field of BCIs, as it allows evaluating their impact in real contexts and advancing in the development of safe, reliable, and scalable devices.

> The development of electroencephalography by German neurologist Hans Berger in 1924 allowed recording human brain electrical activity for the first time, opening a new field for the study of neural signals.

PROBLEMS THEY SEEK TO SOLVE

In line with the advance of new technologies, the development of BCIs is being driven mainly by their potential to address significant challenges in the field of health, inclusion, and interaction with digital technologies.

One of the most relevant application fields is neurological rehabilitation. Millions of people worldwide live with motor disabilities caused by spinal cord injuries, cerebrovascular accidents, or neurodegenerative diseases. In these cases, access to BCIs can offer an alternative to reestablish communication between the brain and external devices, allowing control of prostheses, exoskeletons, or assistance systems through neuronal activity.

Another highly relevant area is assisted communication. For people with severe speech disorders or locked-in syndrome - a condition in which patients remain conscious but lose the ability to move or speak - BCIs can represent a fundamental communication pathway. Through decoding brain signals associated with the intention to write or speak, these interfaces allow for generating text or interacting with digital systems, giving the user a form of expression and autonomy they have lost.

Beyond their medical applications, BCIs can also play a growing role in the development of new human-machine interfaces. As digital systems become more complex, the need arises to develop more efficient and natural interaction methods. Interfaces based on neural signals could complement or, in some cases, substitute traditional modalities such as keyboard, mouse, or voice commands, especially in environments where these options are limited.

NEUROLOGICAL REHABILITATION

Spinal cord injuries
Stroke
Paralysis

ASSISTED COMMUNICATION

Locked-in syndrome
Speech disorders

HUMAN-MACHINE INTERACTION

Natural interfaces

GROWING RELEVANCE IN THE GLOBAL TECHNOLOGY ECOSYSTEM

The potential of BCIs has generated growing interest in the global technological innovation ecosystem. In recent years, the field of neurotechnology has begun to attract significant investments, both from technology companies and venture capital funds and public research programs.

According to estimates cited by the World Economic Forum (WEF), the global BCI market could expand from approximately $1.74 billion in 2022 to nearly $6.2 billion in 2030, with a compound annual growth rate of 17.5%.

The dynamism of the sector is also reflected in the expansion of the global neurotechnology innovation ecosystem. Recent estimates indicate that there are up to 680 companies worldwide working on technologies related to brain-computer interfaces.

This growth evidences the interest of startups, academic, and research centers in developing new applications in neurotechnology. The ecosystem is characterized by strong collaboration between the mentioned scientific disciplines, as well as interaction between academic research, industrial development, and clinical applications.

+680
Companies working on neurotechnology worldwide

$6.2B
Projected market for 2030

17.5%
Compound annual growth rate

INTEREST FROM GOVERNMENTS AND INTERNATIONAL ORGANIZATIONS

In line with their potential in areas such as public health, inclusion of people with disabilities, and development of new industries based on neurotechnology, the advance of brain-computer interfaces has begun to capture the attention of governments, international organizations, and national science and technology systems. In the last two decades, different countries have promoted research programs oriented toward strengthening scientific capabilities in neuroscience, AI, and biomedical engineering - the technological basis of BCIs. These efforts have materialized research funding initiatives, technology transfer programs, and the development of regulatory frameworks for advanced medical devices.

In advanced economies, public interest in neurotechnologies has been expressed through large scientific research programs. Programs such as the BRAIN Initiative in the United States or the Human Brain Project in Europe have driven significant investments in neuroscience, neural signal processing, and brain-machine interfaces. These initiatives have contributed to accelerating basic and applied research in the field, generating advances in neural sensors, brain signal decoding algorithms, and neural stimulation technologies. Likewise, multilateral organizations and international entities have begun to debate the necessary ethical and regulatory frameworks for the responsible development of these technologies.

In Latin America and the Caribbean, the development of BCIs is still in an incipient stage compared to North America, Europe, or Asia. However, several countries have begun to develop research capabilities in neuroengineering, robotics, and neural signal processing. These efforts are mainly concentrated in universities, research centers, and scientific consortia working on applications oriented toward neurological rehabilitation, assisted communication, and development of assistive technologies.

In this context, understanding the evolution of BCIs is particularly relevant for multilateral organizations and development actors. As neurotechnology's advance toward clinical and commercial applications, the need arises to anticipate their implications for health systems, regulatory frameworks, and innovation policies.

04

GLOBAL INNOVATION ECOSYSTEM IN BCI

The development of BCIs is part of a global innovation ecosystem characterized by intersection between scientific research, private investment, and growing public interest. This ecosystem combines technological actors, academic institutions, and government programs that, together, are accelerating the transition of BCIs from experimental applications toward clinical and commercial solutions. Understanding who leads this process and where innovation is concentrated is key to identifying strategic opportunities, particularly in the context of Latin America and the Caribbean.

MARKET SIZE AND PROJECTIONS

As previously indicated, consistent with WEF estimates - which project an expansion close to 17.5% toward 2030 - the projected growth responds to the convergence of multiple factors.

First, the advancement of clinical applications, particularly in neurorehabilitation, assisted communication, and treatment of neurological diseases, is driving growing demand in health systems. At the same time, the convergence of BCIs with digital technologies such as AI, virtual reality, and robotics opens new opportunities in sectors such as industry, entertainment, and wellness. Finally, the sustained increase in public and private research and development investment is accelerating innovation and contributing to reducing technological barriers.

In addition to market growth, the ecosystem shows significant expansion in terms of actors. Recent estimates suggest the existence of hundreds of companies and startups working on BCI-related technologies, along with accumulated investment of billions of dollars. This dynamism positions BCI as both a technology and an emerging field within the knowledge economy, with potential to generate new industries based on neurotechnology.

MAIN COMPANIES

Currently, the BCI innovation ecosystem is led by a set of technology companies developing solutions with different approaches: from high-resolution invasive implants to non-invasive devices oriented toward consumers.

Among the main sector actors, *Neuralink* stands out, a U.S. company based in California, dedicated to developing brain implants with thousands of electrodes capable of recording and stimulating neuronal activity. Its approach prioritizes medical applications, such as treatment of paralysis and neurodegenerative diseases, with a long-term vision oriented toward expanding cognitive capabilities and deepening the interaction between the human brain and AI systems.

Another relevant actor is *Synchron*, a company originated in Australia, that has developed a minimally invasive interface, the *Stentrode*, implanted through cerebral blood vessels. This approach significantly reduces the risks of open surgery and has allowed advancement in clinical trials in humans, positioning the company among the first to achieve functional implantations in patients.

In parallel, *Precision Neuroscience*, a company based in New York develops cortical interfaces based on ultrathin sheets of microelectrodes that adapt to the brain surface without penetrating tissue. This approach seeks to balance high signal resolution with a lower degree of invasiveness, which could favor its adoption in a broader spectrum of clinical applications.

For its part, *Paradromics*, based in Austin, Texas, works on high-resolution interfaces oriented mainly toward communication in patients with severe motor disabilities. Its devices employ microelectrode arrays capable of recording neuronal activity at the individual level, enabling more precise decoding of brain signals.

These companies reflect the diversity of technological approaches characterizing the BCI field, as well as the growing competition to develop increasingly safe, precise, and scalable solutions. At the same time, they highlight the central role of the private sector in accelerating innovation, especially in the more advanced stages of development and commercialization processes.

NEURALINK (USA)

- High-resolution brain implants
- First human implantation (2024)
- Medical and cognitive focus

SYNCHRON (Australia)

- Minimally invasive Stentrode
- Vascular implantation
- High clinical safety

PRECISION NEUROSCIENCE (USA)

- Ultra-thin cortical interfaces
- Lower invasiveness
- High signal resolution

PARADROMICS (USA)

- Communication for severe paralysis
- Microelectrode arrays
- Precise signal decoding

ACADEMIC AND RESEARCH CENTERS

The development of BCIs is deeply linked to the role of academic research. Universities and research centers play a fundamental role in knowledge generation, development of new technologies, and training specialized talent. Among the leading institutions is Stanford University, where research teams have achieved significant advances in decoding neural signals to restore communication in patients with paralysis. These developments have demonstrated the possibility of translating brain activity into text or voice with speeds close to natural communication.

The Massachusetts Institute of Technology (MIT) also plays a key role in the field, with research ranging from development of non-invasive neural sensors to integration of BCIs with robotic and AI systems. Its contributions have been fundamental to advancing the understanding of brain-machine interaction.

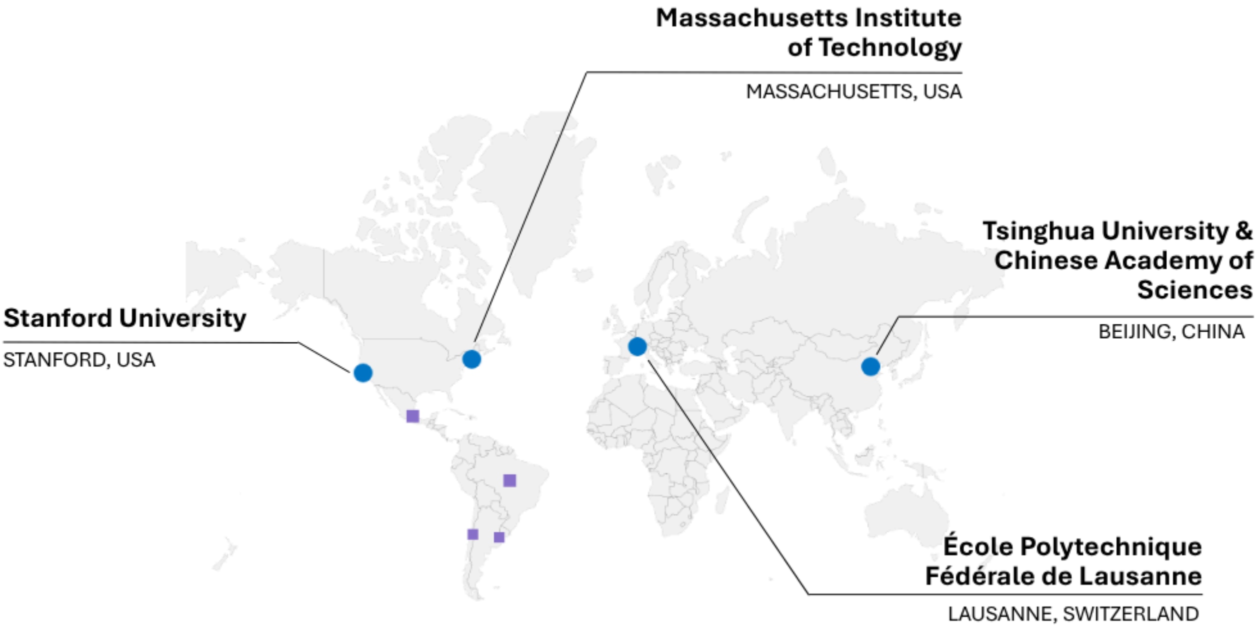
In Europe, the École Polytechnique Fédérale de Lausanne (EPFL), in Switzerland, has led pioneering projects in neurorehabilitation, combining BCIs with electrical stimulation and robotics to restore motor functions in patients with spinal cord injuries. These studies have demonstrated concrete advances in mobility recovery, consolidating the therapeutic potential of this new technology.

The interaction between these academic centers and the private sector is a distinctive feature of the BCI innovation ecosystem. Many startups and technology companies emerge from university research, facilitating knowledge transfer, and accelerating the development of practical applications.

In Latin America and the Caribbean, while there are not yet centers with the same level of scale or funding as the main global hubs, emerging academic capabilities are observed in neuroscience, bioengineering, and neural signal processing, constituting a relevant base for the future development of brain-computer interfaces.

In Brazil, institutions such as the Federal University of Rio Grande do Norte and the Edmond and Lily Safra International Institute of Neurosciences have led research in neurorehabilitation and control of robotic devices through brain signals. Chile's government, for its part, along with groups from the University of Chile, have developed non-invasive BCI applications oriented toward assisted communication and neurological rehabilitation. In Mexico, the National Autonomous University of Mexico (UNAM) and the National Polytechnic Institute work on developing systems based on electroencephalography for control of human-machine interfaces. In Argentina, groups linked to the National Scientific and Technical Research Council have contributed to advancement in computational neuroscience and neural signal analysis.

Although these initiatives are mostly concentrated in early research stages or experimental prototypes, they reflect a consolidating scientific ecosystem, with growing interdisciplinarity and incipient links with clinical applications. In this context, international cooperation, access to advanced infrastructure, and strengthening of technology transfer mechanisms appear as key factors to scale these capabilities and facilitate the region's insertion in the global BCI innovation ecosystem.



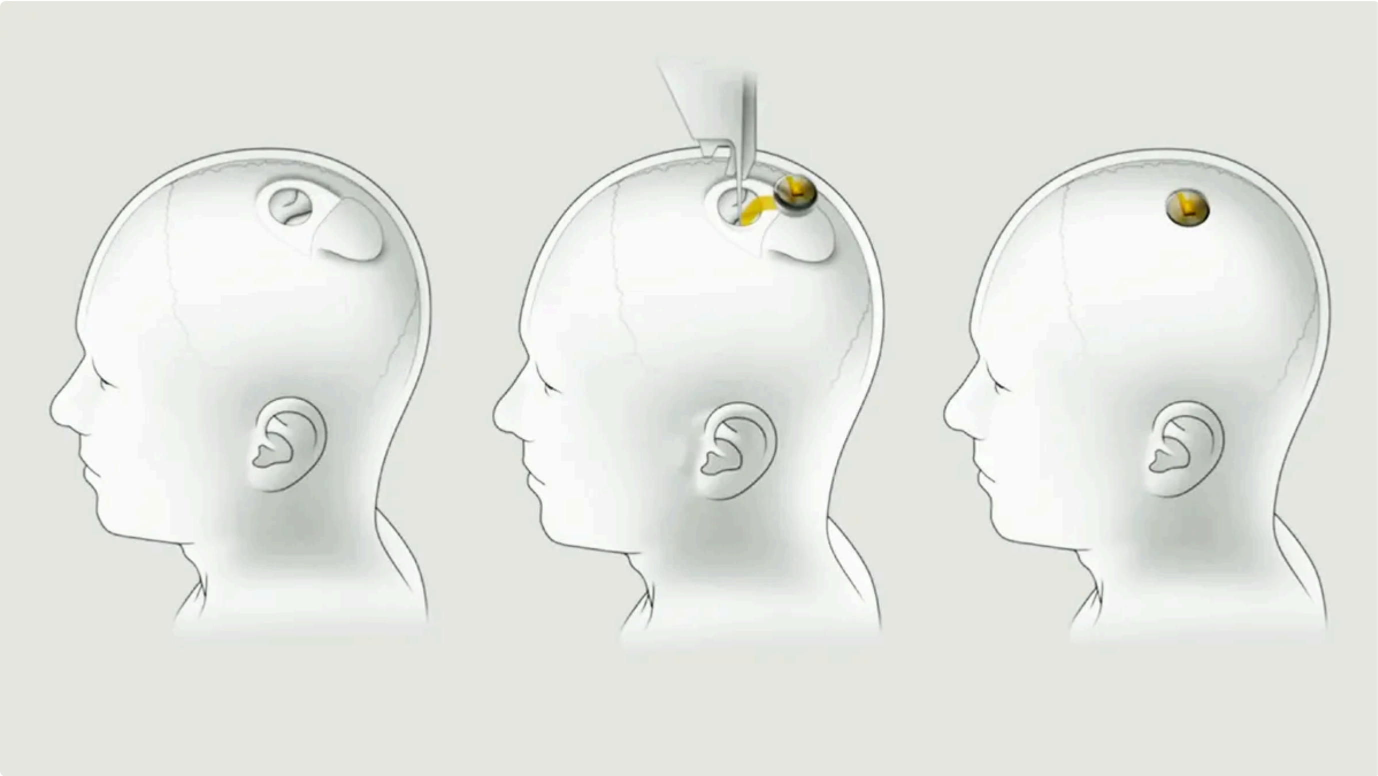
Leading Hubs (blue) and Emerging Centers in Latin America (purple)

GEOPOLITICS OF NEUROTECHNOLOGY

The development of BCIs presents a relevant geopolitical dimension, since, like any emerging technology it is embedded in the capabilities of countries and regions to provide more or fewer resources to stimulate its development.

In this sense, currently the United States maintains global leadership in the development of brain-computer interfaces, particularly in translation from research toward clinical and commercial applications. This leadership is sustained by the combination of excellent universities, a dynamic startup ecosystem, constant investment, and an active regulatory framework that has begun to enable human trials.

A recent milestone is the advancement of clinical trials with implantable devices. In 2024, after authorization from the U.S. Food and Drug Administration (FDA), Neuralink performed its first implant in a human patient as part of the Precise Robotically Implanted Brain-Computer Interface (PRIME) study, the first FDA-approved clinical trial in humans. This device allowed the patient to control a computer, including cursor, typing, and navigation, through brain signals, marking a turning point in the clinical validation of these technologies.



Neuralink's brain-computer interface technology inserts electrodes into the brain and then uses a chip to communicate with computers located outside the skull. Screenshot by Stephen Shankland/CNET

From this advance, the ecosystem has rapidly evolved toward more complex trials. In 2025, feasibility studies were launched to extend these capabilities to control physical devices, such as robotic arms, through implantable neural interfaces. In parallel, other North American companies have advanced in clinical trials oriented toward restoring speech in patients with severe paralysis, consolidating the focus on high clinical impact applications.

China, for its part, has emerged as a key actor in the development of neurotechnologies, with significant investments in research and a state strategy oriented toward strengthening its scientific and technological capacity. The country has advanced both in basic research and experimental applications, consolidating its position as a relevant competitor in the BCI field. A recent milestone supporting this advance is the approval, in 2026, of the first brain-computer interface device authorized for clinical use outside experimental trials, intended to restore hand movement in patients with paralysis, positioning the country at the forefront in the transition toward commercial medical applications.

In parallel, research led by the Chinese Academy of Sciences has demonstrated that patients with tetraplegia can control intelligent wheelchairs or robotic devices through brain signals, evidencing progress in functional BCI applications. In turn, studies reported in Nature magazine show that implantable devices developed in China have allowed patients with severe disabilities to interact with digital environments, including control of video games, reflecting advances in high-resolution interfaces and usability.

Europe, for its part, maintains a prominent role in scientific research, with a strong focus on clinical, ethical, and regulatory applications. Research programs funded by the European Union have driven advances in neuroscience and medical technologies, positioning the region as a reference in the responsible development of neurotechnologies.

Additionally, the bloc has played a key role in defining ethical and regulatory frameworks for neurotechnology's. The EU has promoted guidelines on neural data privacy, informed consent, and responsible use of emerging technologies, positioning itself as a global reference in technological governance.

In contrast to these cases, although there are considerable scientific capabilities in countries such as Brazil, Chile, Mexico, and Argentina, the participation of Latin America and the Caribbean in the BCI area is still incipient. These capabilities are mainly concentrated in academic research and experimental development, with less presence in the business sphere and technology commercialization. However, the growing availability of scientific talent and the strengthening of innovation ecosystems open opportunities for greater integration of the region in global BCI development.

The geopolitics of neurotechnology reflect growing competition to lead a field that could have significant implications in health, productivity, and innovation. For developing economies, the present challenge lies in strengthening their scientific capabilities, promoting international collaboration, and designing policies that facilitate responsible adoption of these emerging technologies.

05

CURRENT AND EMERGING APPLICATIONS OF BCIs

The recent advance of BCIs has allowed their transition from experimental environments toward clinical applications and functional use cases, particularly in health, communication, and device control. While many applications are still in validation phases, there is growing evidence of their impact on patients and their potential to extend to other sectors.

HEALTH AND NEUROLOGICAL REHABILITATION

The health sector constitutes the main application area of BCIs, especially in treatment of neurological conditions affecting mobility, communication, and autonomy.

In patients with severe paralysis, BCIs allow recovering motor functions through decoding movement intention and its translation into commands for external devices. Recent clinical trials have demonstrated that people with quadriplegia can control computers, cursors, or robotic devices solely through brain signals, representing a significant advance in terms of functional autonomy.

In the case of amyotrophic lateral sclerosis (ALS), where progressive loss of muscle control limits communication capacity, BCIs have demonstrated particularly relevant results. Recent clinical studies have permitted ALS patients to recover the ability to communicate through systems that translate neural signals into text or synthesized voice, with precision levels close to natural language.

In post-stroke rehabilitation processes, BCIs are being used to stimulate neuroplasticity. Through detection of motor intention, these systems can activate exoskeletons or functional electrical stimulation systems, facilitating reorganization of damaged neural circuits and improving motor recovery.

Another expanding field is the development of neuroprosthetics, which combine neural recording and stimulation to restore sensory or motor functions. These technologies allow, for example, users to control robotic arms or partially recover tactile sensitivity, opening new possibilities in advanced rehabilitation.

Together, these applications reflect that BCIs are moving from being experimental tools to soon becoming clinical technologies with direct impact on quality of life.

AUGMENTED COMMUNICATION

One of the most disruptive advances in the BCI field is observed in communication restoration, particularly through so-called speech decoding. Recent research has demonstrated BCIs' capacity to decode both attempted speech and internal speech directly from brain activity. In studies published in 2025, research teams achieved real-time translation of neural signals associated with complete words and phrases in patients with paralysis. This advance represents a qualitative change from previous systems, which depended on slower interfaces or was based on character selection.

In parallel, systems have been developed that can convert brain signals into synthesized speech with intonation and rhythm, generating an experience close to natural conversation. These developments significantly reduce latency and improve communicative fluency, one of the main historical challenges of BCIs.

Another relevant line is writing through thought, where users can generate text directly from neural signals. Clinical trials have demonstrated increasingly high writing rates, progressively approaching speeds comparable to conventional communication.

These innovations position BCIs as a key technology for restoring communicative agency, with profound implications not only in health but also in social inclusion.

NEUROPSYCHIATRY AND MENTAL HEALTH

In the case of neuropsychiatry, the use of BCIs has also advanced significantly in recent years, particularly in the development of personalized closed-loop neuromodulation systems. A notable case is a clinical study led by the University of California, where an adaptive deep brain stimulation system was implemented to treat resistant depression. This approach allowed adjusting stimulation in real time based on patient-specific neural biomarkers, achieving clinically significant reductions in depressive symptoms.

Likewise, devices developed by the company NeuroPace, originally approved for epilepsy treatment, are being explored in psychiatric applications. These systems record brain activity and apply stimulation only when they detect patterns associated with crises or dysfunctions, constituting an advanced example of personalized medicine based on neural data.

In the field of obsessive-compulsive disorder (OCD) and anxiety, research funded by the U.S. National Institute of Health has explored the use of BCI-based neurofeedback to modulate neural circuits associated with emotional regulation. Although these developments are still in early phases, they evidence a transition toward more precise, adaptive, and less invasive treatments.

ADVANCED HUMAN-MACHINE INTERFACES

BCIs are enabling new forms of direct interaction between the human brain and physical or digital systems, with applications extending beyond the clinical field.

A relevant example is the work developed at MIT, where researchers presented a non-invasive interface capable of controlling complex robotic devices in real time, including Spot, Boston Dynamics' quadruped robot. This system combines electroencephalography with machine learning algorithms to translate motor intentions into precise commands, evidencing advances in neural signal-based robotic control.

In the field of advanced rehabilitation, EPFL has developed integrated systems combining BCIs with electrical stimulation and exoskeletons. These systems have allowed patients with spinal cord injuries to recover basic motor functions, such as standing or walking with assistance, demonstrating the viability of brain-machine interfaces in real clinical environments.

For its part, the Defense Advanced Research Projects Agency (DARPA) has promoted programs oriented toward developing neural interfaces for controlling complex systems in operational contexts, including drones and autonomous platforms. These programs reflect strategic interest in high cognitive efficiency interfaces for high-demand environments.

> These innovations position BCIs as a key technology for restoring communicative agency, with profound implications not only in health but also in social inclusion.

Together, these cases present an evolution toward more natural and intuitive interfaces, where interaction with machines is based directly on cognitive intention.

EMERGING APPLICATIONS

Beyond their current applications, BCIs are beginning to expand toward new areas with clear transformative potential.

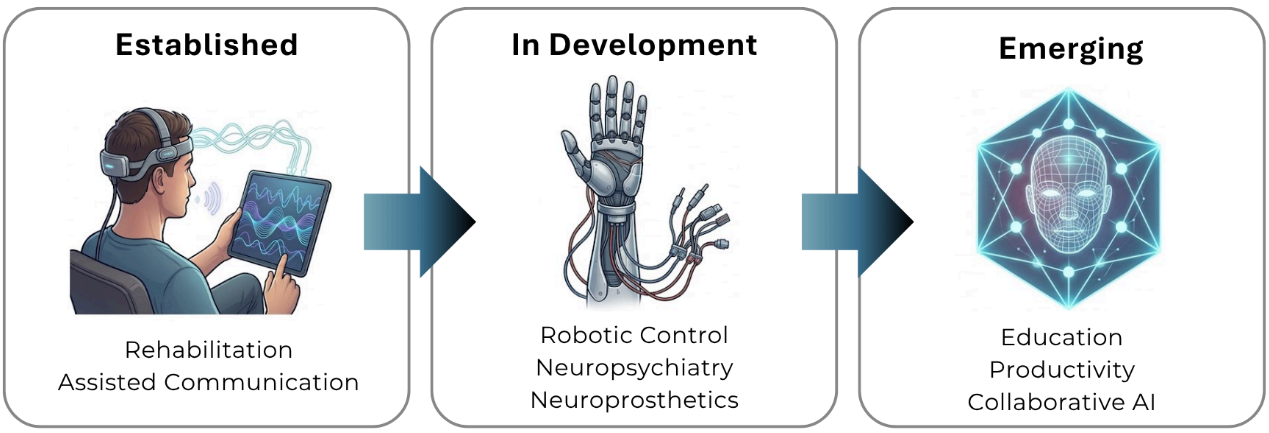
In the field of education and cognitive training, various research shows that BCI-based neurofeedback systems can improve attention and performance in complex cognitive tasks. These advances open the possibility of developing adaptive educational environments, adjusted in real time from neural data.

In the field of productivity and cognitive monitoring, companies like Neurable have developed non-invasive devices capable of measuring concentration levels and cognitive load in work contexts. Using machine learning, these systems identify performance patterns and allow for optimizing individual productivity.

In the defense and aerospace industries, programs from the Defense Advanced Research Projects Agency have explored the use of BCIs to improve human-machine interaction in complex environments, including team coordination and control of autonomous systems. These applications seek to reduce cognitive load and strengthen real-time decision-making.

Finally, one of the most relevant developments is the convergence between BCIs and AI. Recent initiatives, such as those promoted by OpenAI together with neurotechnology startups like Merge Labs, aim to develop non-invasive interfaces that enable direct interaction between humans and AI systems through neural signals. This approach could redefine the human-computer interaction paradigm, giving rise to more direct, fast, and natural forms of linkage with digital systems.

Spectrum of BCI Applications



(AI-generated images)

06

IMPLICATIONS FOR DEVELOPMENT AND OPPORTUNITIES FOR LATIN AMERICA AND THE CARIBBEAN

BCIs are beginning to emerge as a technology with potential impact on the development agenda of Latin America and the Caribbean, particularly in areas such as social inclusion, health, scientific development, and productive transformation. While, as mentioned, the region does not currently lead the technological frontier in this field, it has incipient capabilities and opportunity spaces for strategic insertion, especially if public policies, investment in science, and international cooperation are articulated. In this context, the challenge is not only the adoption of technology but how to orient its development toward regional priorities, maximizing its social and economic impact.

INCLUSION AND DISABILITY

BCIs present high potential as assistive technologies oriented toward improving the quality of life of people with disabilities, particularly those with motor or speech limitations. In Latin America and the Caribbean, where significant gaps persist in access to rehabilitation technologies and assistive devices, these solutions could contribute to reducing structural inequalities in autonomy and social participation.

In the region, there are already research lines oriented toward developing non-invasive interfaces based on electroencephalography with applications in wheelchair control, communication interfaces, and basic assistance systems. Academic institutions in countries such as Brazil, Argentina, Mexico, and Chile have developed functional prototypes in laboratory environments, evidencing an initial technological base upon which to build.

However, adoption of these technologies faces relevant challenges, including device cost, limited availability of specialized services, and the need to adapt solutions to diverse socioeconomic contexts.

In this sense, it is vital to think about BCI development in the region strategically prioritizing approaches of accessibility, low cost, and scalability, aligned with the needs and circumstances of social protection systems.

HEALTH SYSTEMS

The potential of BCIs in the region is particularly relevant in strengthening health systems, especially in the field of neurological rehabilitation. As a region, Latin America and the Caribbean faces a growing burden of neurological diseases, including cerebrovascular accidents, spinal cord injuries, and neurodegenerative diseases, which require prolonged and costly interventions.

BCIs can contribute to improving the effectiveness of rehabilitation processes through approaches based on neuroplasticity and real-time feedback. In several countries across the region, research groups have begun to explore the use of BCIs in combination with robotics and functional electrical stimulation to support motor recovery.

Here too, their effective incorporation into health systems requires overcoming structural barriers, such as service fragmentation, shortage of specialized professionals, and scarcity of technological infrastructure. Likewise, it will be necessary to advance clear regulatory frameworks for evaluation and approval of advanced medical devices, as well as financing schemes that allow their integration into public health systems.

INNOVATION ECOSYSTEMS

The development of BCIs offers an opportunity to dynamize innovation ecosystems in Latin America and the Caribbean, particularly at the intersection between health, AI, and biomedical engineering.

While the number of neurotechnology startups in the region is still limited, this situation is part of a broader trend: the low density of deep tech ventures in the region. Regional innovation ecosystems present strong concentration in digital sectors of rapid scalability, while science-intensive areas, such as biotechnology, medical devices, and neurotechnology, face higher entry barriers associated with capital requirements, infrastructure, and longer development timelines.

Countries such as Brazil, Chile, and Mexico have advanced in creating support programs for science-based ventures, such as the Technological Innovation Program in Small Companies (PIPE) in Brazil, or Start-Up Chile, which could extend to the neurotechnology field. The consolidation of specialized innovation hubs, integrating capabilities in digital health, AI, and medical devices, could accelerate the maturation of the technology and the sector in the region.

For this initiative to succeed, it is key to promote policies that facilitate access to financing, encourage public-private partnerships, and reduce regulatory barriers for experimentation and validation of new technologies.

SCIENTIFIC TALENT AND REGIONAL CAPABILITIES

The development of BCIs depends on highly interdisciplinary capabilities, combining neuroscience, engineering, data science, and medicine. Latin America and the Caribbean have a relevant scientific talent base in these areas, although distributed heterogeneously among countries.

Universities and research centers in the region have developed work lines in cognitive neuroscience, biomedical signal processing, and AI applied to health. These capabilities constitute an important starting point for BCI technology development, although they still face limitations in terms of funding, access to advanced infrastructure, and articulation with the productive sector.

One of the main challenges is the training of interdisciplinary profiles, capable of integrating technical and clinical knowledge. Likewise, talent retention remains a structural problem, due to researcher migration toward ecosystems with greater resources.

Strengthening these capabilities will require investments in higher education, specialized training programs, and strategies to promote regional collaboration, allowing leverage of economies of scale in research and development.

> For Latin America and the Caribbean, understanding these dynamics and anticipating their implications will be fundamental to orienting their development in an inclusive, sustainable manner aligned with the region's priorities.

INTERNATIONAL COOPERATION

Given the emerging and complex character of BCIs, international cooperation represents a central potential in capability development in Latin America and the Caribbean. Articulation with global research networks, as well as participation in international initiatives, can facilitate access to knowledge, infrastructure, and good regulatory practices.

In this context, multilateral organizations can play a strategic role in promoting neurotechnology innovation agendas. This includes financing pilot projects, supporting scientific-technological entrepreneurship ecosystems, and technical assistance for designing regulatory frameworks.

Likewise, regional cooperation can contribute to reducing fragmentation of efforts and generating shared research and development platforms. Initiatives integrating multiple countries would allow advancing toward a critical mass of capabilities, facilitating adoption and adaptation of technologies like BCIs in local contexts.

07

RISKS, REGULATIONS, AND ETHICAL CHALLENGES

The development of BCIs introduces challenges that transcend the technological, encompassing regulatory, ethical, and human rights dimensions. As these technologies advance toward potential clinical applications and commercial uses, it becomes fundamental to anticipate their implications and ensure their responsible development.

In this context, UNESCO has emerged as one of the main international references, promoting specific normative frameworks for neurotechnology governance, while other organizations such as the World Health Organization (WHO) and the Organization for Economic Co-operation and Development (OECD) have begun to outline principles and frameworks oriented toward guiding the responsible development of neurotechnology.

PRIVACY AND NEURAL DATA

One of the most critical challenges associated with BCIs is the management of neural data (neurodata). Unlike other biometric data, these can reveal highly sensitive information about thoughts, emotions, and intentions.

Neurotechnology allows accessing the most intimate mental activity, which requires reinforced protection mechanisms against misuse. In particular, the use of neurodata for commercial purposes—such as marketing or behavioral profiling—raises significant risks in terms of surveillance and manipulation.

In this sense, emerging frameworks propose recognizing neurodata as a differentiated category, subject to stricter standards of consent, storage, and use.

SECURITY AND CYBERSECURITY

BCIs bring new risks in cybersecurity matters, especially in connected or implantable devices. The possibility of unauthorized access or external interference in systems that interact directly with the brain raises unprecedented challenges.

Convergence with AI systems amplifies these risks by increasing the capacity to decode, predict, and eventually modulate neural patterns. As algorithms become more precise in interpreting brain signals, the potential for misuse also expands, including forms of cognitive or emotional influence, induced biases, or alterations in decision-making. These scenarios raise not only technical challenges but also ethical and regulatory ones around mental autonomy and neural privacy.

In this context, it is fundamental to advance toward security by design approaches, integrating protection mechanisms from the initial stages of technological development. This implies, among other aspects, robust encryption of neurodata, secure device authentication, continuous software updating, and implementation of protocols guaranteeing traceability and user control over their information. It will be key to complement these developments with specific regulatory frameworks and international standards that accompany technological evolution and mitigate its emerging risks.

MEDICAL DEVICE REGULATION

BCIs also raise substantive challenges for traditional regulatory frameworks, by integrating implantable devices, advanced software, and AI into highly complex systems. While their clinical applications are usually subject to evaluation as medical devices, many of their functionalities, particularly those based on adaptive software or digital connectivity, exceed conventional regulatory schemes.

The WHO has emphasized the need to strengthen regulatory frameworks for advanced medical technologies, highlighting the importance of guaranteeing safety, efficacy, and continuous monitoring standards throughout the device lifecycle. In the case of BCIs, this implies expanding the evaluation focus: not only the implantable hardware or sensors, but also the algorithms that process neural signals, especially when they can be modified through machine learning. Validation of systems that evolve over time introduces additional challenges in terms of certification, reproducibility, and traceability.

In this context, merging between medical devices and digital technologies demands advancing toward more dynamic and adaptive regulatory approaches. This includes progressive or conditional approval mechanisms, robust post-commercialization surveillance schemes, and specific frameworks for software as a medical device (SaMD). Likewise, it becomes key to incorporate algorithmic audits, explainability requirements, and data governance standards that allow mitigating risks associated with biases, systemic failures, or unforeseen behaviors.

In Latin America and the Caribbean, these challenges are amplified by the heterogeneity of regulatory capabilities and normative fragmentation. Strengthening health agencies, promoting regional harmonization, and developing technical capabilities to evaluate complex technologies will be necessary conditions for safe and effective BCI adoption. Added to this is the need to generate international cooperation frameworks, promote regulatory experimentation spaces (such as sandboxes), and articulate the public sector with the scientific-technological ecosystem, to accompany the pace of innovation without compromising user protection.

EQUITY AND ACCESS

The development of BCIs raises significant risks in terms of equity and access, especially in regions with structural inequalities such as Latin America and the Caribbean. Given their high cost, technological complexity, and dependence on specialized infrastructure, there is a risk that these solutions remain restricted to limited segments of the population.

The OECD has warned that emerging knowledge-intensive technologies, such as neurotechnology, tend to concentrate in contexts with greater scientific and financial capabilities, which can deepen existing gaps if adequate public policies are not implemented.

Along the same lines, WEF has pointed out that unequal access to technologies capable of improving cognitive or functional capabilities could generate new forms of inequality, both between countries and within them.

For Latin America and the Caribbean, this scenario demands a proactive approach oriented toward promoting inclusive innovation. This implies incorporating accessibility and affordability criteria from the design stages, developing financing models that facilitate their integration into public health systems, and exploring mechanisms such as innovative public procurement or progressive coverage schemes. Likewise, strengthening local capabilities, both in research, development, regulation, and production, is key to reducing technological dependence, participating in emerging value chains, and guaranteeing more equitable and sustainable access to these advances.

AUTONOMY, CONSENT, AND HUMAN AGENCY

Brain-computer interfaces introduce fundamental challenges in relation to individual autonomy, informed consent, and human agency, by enabling forms of direct interaction with brain activity. These technologies not only allow recording neural signals but, in certain cases, can influence them, raising questions about the limits of technological intervention in the human mind.

UNESCO has warned that neurotechnology can impact essential dimensions such as freedom of thought, personal identity, and mental integrity. In this sense, it emphasizes the need to establish specific safeguards to protect the so-called "cognitive sphere," incorporating ethical principles that contemplate risks such as involuntary manipulation, extraction of sensitive information, or erosion of autonomy.

Along the same lines, the WHO emphasizes that, in the case of advanced medical technologies, informed consent must adapt to contexts of high technical complexity and uncertainty. This implies not only communicating immediate benefits and risks, but also considering long-term effects, possible system updates, changes in device behavior, and management of generated neural data. Likewise, it becomes relevant to contemplate dynamic consent mechanisms, allowing users to maintain continuous control over technology use.

In this context, the concept of neurorights has gained strength, oriented toward protecting mental privacy, personal identity, autonomy, and free will against technologies capable of accessing or influencing brain activity. This approach promotes the incorporation of new normative categories, such as protection of neural data or prohibition of undue cognitive interferences, and reflects the need to update traditional ethical and legal frameworks to respond to challenges posed by confluence between neuroscience and digital technologies.

08
PUBLIC POLICY IMPLICATIONS

The development of BCIs introduces an emerging agenda for public policies that combines dimensions of health, innovation, regulation, and human rights. In Latin America and the Caribbean, these implications acquire a particular relevance, given that the region faces structural challenges, such as gaps in access to health services and technological capabilities, and opportunities linked to incorporation of frontier technologies simultaneously.

More than a linear technological adoption process, BCIs need to be understood as part of a broader transformation in the relationship between science, technology, and development, where the capacity to anticipate risks, build adequate institutional frameworks, and orient innovation toward social objectives will be determinant. In this context, public and multilateral actors have a key role in configuring this agenda.

INVESTMENT IN RESEARCH AND DEVELOPMENT IN NEUROTECHNOLOGY

The recent advance of BCIs highlights the importance of having robust capabilities in research and development (R&D), especially in highly interdisciplinary fields articulating neuroscience, biomedical engineering, data science, and AI. In Latin America and the Caribbean, while there are centers of excellence in these areas, capabilities often present in a fragmented manner, with limitations in sustained financing, specialized infrastructure, and critical mass of researchers, making consolidation of integrated ecosystems difficult.

From a public policy perspective, neurotechnology evidences the need to strengthen science, technology, and innovation systems with a long-term strategic vision. This implies promoting greater articulation between basic research, applied development, and technology transfer, as well as designing instruments that support the entire innovation cycle. The complexity and cost of these technologies also underscore the importance of generating economies of scale, both at national and regional levels, through research consortia, shared platforms, and international cooperation schemes.

At the same time, this field exposes persistent structural tensions in the region's R&D systems. Among them, difficulty in sustaining research trajectories in high-risk and uncertainty areas, limited availability of long-term financing, and weak linkage between scientific production and its application in productive or clinical environments. Overcoming these gaps will require not only greater resources, but also improvements in innovation system governance, adequate incentives for public-private collaboration, and development of institutional capabilities oriented toward adoption and scaling of complex technologies.

REGULATORY FRAMEWORKS FOR NEURODATA AND BCI TECHNOLOGIES

The emergence of BCIs raises questions about the capacity of existing regulatory frameworks to adapt to technologies operating at the interface between the biological and the digital. In particular, neurodata introduces a category of information that challenges traditional definitions of personal data, by involving intimate dimensions of cognitive activity.

In Latin America and the Caribbean, where data protection frameworks have advanced unevenly, the development of neurodata raises the need to review key concepts such as consent, data ownership, and secondary uses. At the same time, medical device regulation faces the challenge of incorporating technologies that combine hardware, software, and AI into dynamic and adaptive systems.

This scenario highlights the importance of advancing toward more flexible and anticipatory regulatory approaches, capable of accompanying innovation without generating normative gaps. It also highlights the need to strengthen the technical capabilities of regulatory agencies, which will need to evaluate increasingly complex technologies.

INTEGRATION INTO HEALTH SYSTEMS AND CLINICAL EVIDENCE

The most advanced applications of BCIs currently concentrate in the health field, particularly in neurological rehabilitation and assistance to people with disabilities. Their development raises concrete questions about the region's health systems' capacity to incorporate high-complexity technologies, not only from a technical standpoint but also organizational, financial, and regulatory.

In Latin America and the Caribbean, these challenges are accentuated by health system fragmentation, access gaps, and limited availability of specialized services. BCI incorporation requires, in addition to technological infrastructure, the development of specific clinical capabilities, interdisciplinary professional training, and adaptation of care models to effectively integrate this type of solution. Added to this is the need to define prioritization and coverage criteria, considering their high cost and potential impact in terms of quality of life.

In this context, local evidence generation acquires a central role. The epidemiological, institutional, and socioeconomic conditions of the region differ from those in which these technologies are initially developed and validated, making it essential to evaluate their clinical effectiveness, cost-effectiveness, and operational viability in specific contexts. This includes designing regional clinical studies, strengthening health technology assessment agencies, and incorporating real-world data to orient decision-making.

Together, these elements reinforce the importance of articulating clinical research with health policies and promoting gradual and strategic BCI integration within health systems already facing multiple pressures. More than isolated adoption, it involves incorporating these technologies within the framework of broader system strengthening strategies, contemplating financial sustainability, equity in access, and continuous improvement in care quality.

INNOVATION ECOSYSTEMS AND PRODUCTIVE DEVELOPMENT

The development of BCIs highlights the role of innovation ecosystems as spaces where scientific capabilities, entrepreneurship, and productive development come together. In Latin America and the Caribbean, these ecosystems present heterogeneous maturity levels: while advances are observed in digital sectors, lags persist in science-intensive areas, such as neurotechnology, which require greater investments, specialized infrastructure, and interdisciplinary articulation.

The nature of BCIs strains traditional entrepreneurship models in the region. These demand developments with long cycles, high technological uncertainty, and strong capital requirements, which demands more sophisticated financing instruments, such as patient capital, public-private funds or co-investment schemes, and frameworks facilitating effective knowledge transfer from academia toward the productive sector. Likewise, the availability of testing environments, regulatory capabilities, and market access is key to scaling this type of innovation.

At the same time, this field opens opportunities for productive diversification, by enabling the emergence of new industries linked to digital health, advanced medical devices, and AI. Consolidation of these sectors will depend largely on the capacity to articulate innovation policies with economic development strategies, promoting productive linkages, supplier development, and insertion into global value chains.

ETHICAL STANDARDS AND REGIONAL GOVERNANCE

The development of BCIs highlights the importance of international cooperation as a mechanism to access knowledge, resources, and capabilities that can hardly be developed in isolation. The technical complexity and interdisciplinary character of these technologies make collaboration between countries, institutions, and sectors a central component for their advancement.

For Latin America and the Caribbean, cooperation represents not only a pathway for integration into global innovation networks but also a tool to reduce gaps and strengthen endogenous capabilities. Participation in international initiatives can facilitate access to research infrastructure, training specialized talent, and technology transfer, as well as development of common standards.

In this context, multilateral organizations like the IDB can play a strategic role in articulation of regional agendas, resource mobilization, and knowledge generation. Their capacity to act as a bridge between countries, sectors, and disciplines is particularly relevant in an emerging and highly complex field such as BCIs, where coordination and cooperation are key conditions for balanced and sustainable development.

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CONCLUSION

Brain-Computer Interfaces (BCIs) are consolidating as one of the most relevant emerging technologies at the intersection between neuroscience, AI, and digital systems. Throughout this report, it has been evidenced that their development not only implies significant technical advances but also the opening of a new layer of interaction between human beings and technologies, with profound implications for multiple sectors.

First, BCIs represent a qualitative leap in the evolution of human-machine interfaces, by allowing direct translation of neuronal activity into digital commands. This change expands the horizon of what is possible in terms of interaction, overcoming the limitations of traditional channels—such as keyboard, voice, or touch—and enabling new forms of communication and control based on brain activity.

Second, their potential impact on critical areas such as health, inclusion, and productivity is particularly significant. In the health industry, BCIs are already demonstrating capacity to improve quality of life for people with neurological disabilities, facilitating recovery of motor functions, communication in patients with paralysis, and treatment of neurological and psychiatric disorders. These applications have not only clinical but also social results, by contributing to greater autonomy and inclusion.

Beyond health, BCIs are beginning to project applications in productivity, education, and interaction with advanced digital systems. While many of these applications are still in early stages, their development suggests the possibility of more adaptive work environments, personalized learning systems, and new forms of collaboration between humans and AI systems.

However, this transformative potential is accompanied by significant challenges. As analyzed, BCIs introduce risks in privacy, security, regulation, and equity matters, requiring anticipatory responses from public policies and governance frameworks. Management of neural data, protection of individual autonomy, and guarantee of equitable access emerge as central aspects in the future agenda of this technology.

In this context, the role of Latin America and the Caribbean is defined within a balance between structural challenges and emerging opportunities. On one hand, the region faces limitations in terms of scientific capabilities, financing, and technological infrastructure. On the other, it has relevant assets—such as developing academic systems, public health experience, and expanding innovation ecosystems—that can constitute a base for its participation in this field.

More than positioning itself solely as an adopter of technologies developed in other contexts, the region has the opportunity to define its own approach, oriented toward leveraging BCIs according to its development priorities. This implies not only incorporating these technologies into health systems and inclusion policies but also strengthening local capabilities, promoting research, and participating in the construction of regulatory and ethical frameworks at the international level.

Likewise, the role of multilateral organizations such as the Inter-American Development Bank is key to articulate efforts, mobilize resources, and generate knowledge that allows orienting neurotechnology development in the region. Their capacity to integrate sectoral perspectives, such as health, innovation, and regulation, positions these actors as facilitators of a coherent and sustainable regional agenda.

In perspective, BCIs should not be understood solely as an emerging technology but as part of a broader transformation in the relationship between human and digital. Their evolution will depend not only on scientific and technological advances but also on decisions adopted in public policy, regulation, and governance matters.

In this sense, the challenge for Latin America and the Caribbean is not only to accompany this transformation but to actively participate in its configuration, ensuring that BCI development contributes to objectives of inclusion, well-being, and sustainable development.

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