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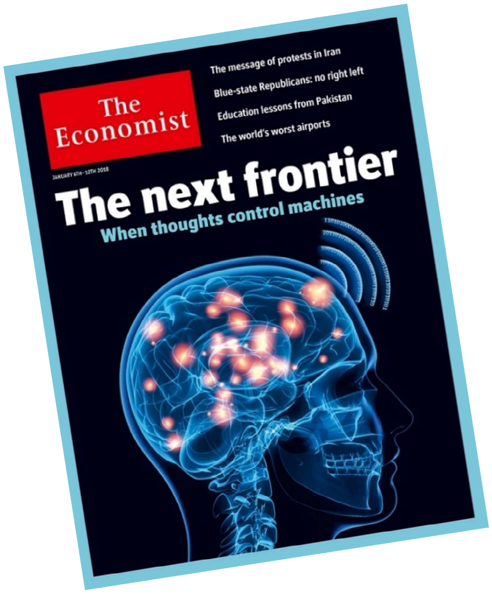
Neurotechnologies: Connecting Human Brains to Computers and Related Ethical Challenges



Cover of The Economist magazine, January 4, 2018[1]

Since 2013, billions of dollars in public funding have been allocated to the study of the human brain[2] in the United States of America (USA)[3], the European Union[4], and China[5]. The international competition for scientific advancement within this field is analogous to the "Space Race", which took place between the USA and the former USSR in the 20th century.

Large-scale initiatives in brain research

European Union: "Human Brain Project", 2013

The Human Brain Project is one of the most ambitious EU research programmes. It involves nearly 500 scientists in 100 European universities. The Human Brain Project also engages American and Chinese entities, in the collaborative study of neuroscience, robotics, computer science, and other related fields. Its funding consists of nearly 1.3 billion dollars to be distributed over 10 years.

USA: "The Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative", 2013.

The BRAIN Initiative seeks to "revolutionize our understanding of the human brain". It currently involves more than 500 laboratories, in the US and abroad, and is funded primarily through public investment estimated at $6 billion dollars, to be distributed over a decade.

China: "Chinese Institute for Brain Research".

Announced in 2016 and launched in 2018, the Chinese Institute for Brain Research is one of the Chinese government's strategic scientific initiatives. Its goal is to study the brain and brain-like intelligence technologies. It expects to have 1200 researchers and technicians by 2022.

Elaborated by:
Raimundo Roberts.
Email: rroberts@bcn.cl
Tel.: (56) 2270 1791
(32) 226 3199

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- Dr. Rómulo Fuentes, Research Director of the Faculty of Medicine, University of Chile
- Dra. María Cecilia Hidalgo, President of the National Academy of Sciences, Chile
- Dr. Rafael Yuste, Director of the NeuroTechnology Center, Columbia University in New York City, USA.

This governmental support for human brain research has been marked by previous scientific advances. Between 2009 and 2013, 16% of articles published around the globe focused on brain. This has increased by 3.9% per year[6], with the USA., EU, and China leading research activities. This momentum could be thought of as the natural progression of behavioural studies aiming to unravel the unknown mechanisms behind the interaction of billions of neurons that make up the human brain.

Impressive innovations have already been developed to facilitate communication between the brain and electronic devices. There now exist orthoses and prostheses that are relatively effective for the treatment of Parkinson's disease, deafness, blindness and other disabilities and pathologies.

With more than a billion people with disabilities in the world[7] (and approximately three million living in Chile[8] alone), this provides significant opportunity to improve the lives of many through technology. There are many other applications of neurotechnologies in healthy people, which are currently being pursued by private business and government. These include fields that vary from defence, to entertainment, to the enhancement of cognitive and intellectual capacities.

These large-scale projects, promoted by several international governments, have set a goal for this new decade to understand the human brain and apply that knowledge. However, neurotecnologies provide more than novel opportunities: in 2013, a study by the European Brain Council estimated that the direct and indirect costs incurred in treatments associated with brain disorders is almost 800 billion Euros. This figure is higher than that spent on cardiovascular diseases and cancer combined[9]. By 2011, U.S. Senator Newt Gingrich estimated that Alzheimer's disease will cost the U.S. health care system more than $20 trillion by 2050, due to its aging population[10].

Apart from these clinical implications, the possibility for neurotechnology to enable *cognitive augmentation*[11], or build an internal "iPhone" allowing users to connect directly to digital networks without typing on a screen or a keyboard, is of immense economic interest.

In fact, private financing is growing, in many cases covertly, to fund new neurotechnology divisions at companies such as Facebook, Microsoft and Google. Additionally, new companies are being created solely for the development of neurotechnologies, such as Kernel (founded by billionaire Brian Johnson) or Neuralink (by inventor Elon Musk). This new technology race has made headlines around the world, including a special issue of The Economist in January 2018[12], focused on superhumans and artificial intelligence.

These developments have posed ethical and regulatory challenges that urgently require a response. Is the brain the ultimate safeguard of human intimacy and integrity? Should it be? What limits should there be to protect personal privacy? Would a patient be responsible for assaulting someone with a prosthetic device (a prosthesis), if he or she does not have full control over it? How should brain information for commercial purposes be regulated? How should access to technologies that enable the intellectual enhancement of people be regulated?

Ethical and policy discussion around these issues are occurring in many different countries, as they seek to build an urgently needed framework through which to address these questions. At stake is the possibility that these new technologies, particularly when used in conjunction with Artificial Intelligence (AI), could redefine what it means to be human.

Meanwhile, the growing knowledge about the nervous system, in concurrence with the development of better equipment and new approaches, has stimulated intense competition in the field of brain and computer interactive devices. Within this field, diverse branches of science and technology converge, including AI, Nanotechnology, and Bioinformatics and collaborate with engineers to translate knowledge of the brain into devices or neurotechnology applications.

What is neurotechnology?

Neurotechnology is "the set of methods and instruments that allow a direct connection between technical devices and the nervous system"[13].

From cochlear implants for deafness and spinal cord stimulators to treat Parkinson's, to brainwave readers for educational uses; new medical and commercial neurotechnology products are being developed every day. Their development, in general, has one goal: to achieve a connection interface between the brain and a computerized device that is capable of responding in real time; that learns, adapts, and manages integrated, closed circuit functioning. Such an accomplishment would be analogous to reaching the moon in the space race .

A more accurate way to define this device or a "Brain-Computer Interface" (BCI) is "a system that measures central nervous system (CNS) activity and converts it into an artificial output (response) that replaces, restores, complements, or enhances the output (response) of the natural CNS and thereby modifies the ongoing interactions between the CNS and its external or internal environment"[14].

It is important to note that, in very controlled environments, a "natural" communication between the brain and an electronic device has already been achieved using BCIs[15].

Due to today's confluence of knowledge and technology, in some of the world's leading centres[16] a person with a motor disability can control prosthetic limbs in a similar way as he would his legs or arms. In fact, the kick-off of the last World Cup in Brazil was performed by one of these patients. Likewise, patients who have sensory disabilities, have been able to receive stimuli directly to their brain so that they can, for example, see, hear or feel tactilely.

Schematically[17], a BCI is a system made up of three elements: 1) sensors connected to the nervous system, which can receive and/or send signals; 2) a processing system (a micro or nano computer) that can distinguish and interpret signals from the nervous system and produce a response; and 3) a device that can perform the action expected in the real world: either sending information to move an object, or stimulating or inhibiting physiological processes (secretions of hormones or enzymes, for example).

Sensors. Sensors can be non-invasive (such as an EEG) or invasive, in which sensors are surgically implanted into the brain. Nano electrodes (e.g. graphene structures) are currently being used within experiments to interface between brain tissue and electronic equipment. Ultimately, such technologies are being developed to replace the current cumbersome electrodes that are commonly employed[18].

Processing systems. Processing systems have made great progress, but still have to resolve several roadblocks: their training is slow or limited, and they must overcome changing environmental and organic conditions, such as deterioration caused by disease (in deafness, for example, the auditory nerve retracts and degrades when it is not stimulated). To overcome this challenge, work is being done in AI, specifically on automated learning, so that the system itself "learns" to discern "significant" brain signals from the large number of total brain signals being produced.

Other areas of knowledge (such as bioinformatics, chemistry, and systems engineering, among others) have been incorporated to develop additional approaches in the brain research race.

Assistive Technologies

In 2011, one billion people in the world (out of 7 billion), had some form of disability. This is about 15% of the population, which in Chile is slightly higher (almost 17%, or about three million).

In many countries, only 5-15% of people who require assistive devices and technologies have access to them. While national and international policy efforts are being made to promote their availability and improve the quality of life for persons with disabilities, scientific and technological research seeks to better understand the human body and to develop more advanced technologies and devices.

These devices are not limited to canes, glasses, wheelchairs or prostheses. They also include cochlear implants (for hearing), robotic limbs, devices that mitigate the motor limitations of Parkinson's disease, and many others.

The growing technological development driven by international "Brain" projects and technology companies may soon lead to the use of non-invasive prostheses. An early example is the "Google Glasses", which allow people to use their gaze to navigate huge databases during the course of their day.

Examples of neurotechnologies

While pursuing this goal for brain-machine connection, other advances have been achieved and made available to people, especially in the field of medicine and assistive technologies[19].

One example is cochlear implants. Severe hearing loss affects more people than those affected by epilepsy, multiple sclerosis, spinal cord injury, stroke, Huntington's, and Parkinson's diseases all together[20], Access to the cochlear implant, therefore, could have a significant impact at a global scale.

These devices began with a highly rudimentary experimental approach in the 1950s. It was not until 1984 in the USA that there use was authorized for adults and finally in 1990, for infants. Initially, cochlear implants consisted of a few electrodes connected to pressure sensors (sound waves), inserted into the auditory nerve. Quality of processors, sensors and electrodes have continuously improved and today, genetic engineering techniques are also in development. Such innovations will enable DNA alterations within affected areas[21],[22] achieving the regeneration of the auditory vestibular nerve.

There has been additional milestone research in the development of devices that treat Parkinson's disease. Dr. Rómulo Fuentes is developing techniques at the University of Chile to stimulate the spinal cord with electrodes to lessen the effects of Parkinson's disease [23]. For this work, Dr. Fuentes is collaborating with Dr. Miguel Nicolelis, whose lab successfully enabled two primates to move a robotic arm with neural signals in 2003[24].

Dr. Fuentes's work is currently being applied to human patients in different countries. In February 2018, the first spinal cord stimulation surgery in Chile was performed [25] on a 71-year-old former PDI policeman. Deep brain stimulation for dystonia was also incorporated into Chilean Public Health System treatments in 2018[26].

The brains of several subjects have been directly connected through BCIs.

This is not science fiction: Dr. Nicolelis and his team were the first to successfully connect the brains of multiple subjects to perform a task. Several monkeys connected to a single BCI worked together, to move a robotic arm in 2015[27]. The connection of several subjects to the same BCI has also recently been achieved with human patients. At the University of Washington, Rahesh Rao's team facilitated direct person-to-person communication[28],[29], [30].

Another rapidly developing technique (including in Chile) is the use of optogenetics. Optogenetics use laser light to activate groups of neurons in genetically modified animals, thus changing their behaviour or sensory perception[31]. Some researchers, such as Parisa Mahmoudi, point out that, just as electric stimulation techniques are used today on people, optogenetic techniques could be used on humans in the not-so-distant future[32]. However, the use of these techniques requires serious ethical analysis, because of the implications they have on the control of human behaviour (see below).

Example of neurotechnology in medicine

Deep Brain Stimulation (DBS), also called "brain pacemaker", is a therapy that consists of chronic electrical microstimulation of deep brain nuclei for the relief of neurological disorders that do not respond to first-line treatments (e.g. pharmacological).

This technology, although invasive, is so effective that there are estimated to be over 40 thousand patients in the world with implanted electrodes for DBS. The treatment is enabled by implanting electrodes in the brain, which provide micro-pulses of electricity at a given frequency, thus modulating brain activity (Benabid, 2003).

Currently, deep brain stimulation is used for the treatment of Parkinson's disease (Benabid et al, 1991; Ashkan, Wallace, Bell, & Benabid, 2004), for dystonia (Hale, Monsour, Rolston, Naftel, & Englot, 2018), for obsessive-compulsive disorder since 2009 (Hirschtritt, Bloch, & Mathews, 2017), and for epilepsy (Li & Cook, 2018). Its effectiveness in the treatment of other pathologies, such as Alzheimer's, is being investigated (Xu & Ponce, 2016). ([1])

([1])

With the available knowledge, prostheses controlled by electrical nerve impulses are also being created[33] . Development of these devices is occurring around the world. They are more simplified as these devices do not involve direct brain-computer connections.

Jorge Zúñiga[34], a Chilean researcher specializing in biomechanics and muscle functioning, developed a mechanical prosthetic hand called "CyborgBeast", which costs less than US$50 and is manufactured with a 3D printer. Zúñiga released the manufacturing rights to his invention, which could help millions of people around the world without access to traditional prosthetics. In 2018 an engineer from Andrés Bello University (Chile) named Mario Olivares designed a

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low-cost prosthetic hand, controlled by electrical impulses from the forearm[35]. It was his final career project and today, it is available in clinics in several South American countries.

These devices are being developed for purposes within the medical field, which has strict ethical regulations for the protection of human beings. However, some neurotechnologies are being applied in contexts beyond medical practice and are commercially available directly to consumers [36].

Several public and private laboratories are working on devices that can transfer thoughts to a screen or a voice mechanism[37],[38]. In fact, a team in California is using implanted electrodes to achieve the synthetic reconstruction of human speech based on patient brain recordings[39]. It is not unreasonable to think that something similar will be achieved very soon with non-invasive techniques.

Many of these devices have applications in education, commerce, and entertainment. They are not solely targeted at patients, but at healthy consumers as well. There are already, for example, home EEG devices marketed to help with concentration. Using sensors that display information about the intensity and composition of brain waves, these devices can determine the user's level of attention, displaying the results through cell phone applications[40]. These devices are intended to support activities such as meditation and biofeedback

Use of neurotechnologies within the defence industry[41] and the videogame industry have demonstrated sustained growth.

Some global market estimates for direct sales of neurotechnology equipment (for health, education and games) amount to more than $8 billion in 2018 alone. This is expected to reach over $13 billion by 2022. These devices are worth between 50 and 500 dollars and are increasingly non-invasive. Patents for new neurotechnologies have more than doubled in the last 10 years[42].

Ethical concerns

Many of these devices are assistive technologies or treatments to cure diseases, and are therefore sold under medical regulatory conditions. Ethical safeguards for the distribution of medical devices and other such instruments are the Universal Declaration of Human Rights (1948)[43], the Nuremberg Code (1947)[44], the Declaration of Helsinki (1964) of the World Medical Association (WMA)[45], and the International Ethical Guidelines for Biomedical Research Involving Human Subjects (2002)[46] put forth by the Council for International Organizations of Medical Sciences (CIOMS) in collaboration with WHO. There are also more specific international agreements, such as the UNESCO International Declaration on Human Genetic Data (2003)[47]. This implies that both research and technological development within medical and health fields are subject to the authorization of Bioethics entities or similar committees.

But in the case of products designed for nonmedical purposes, no specific regulation has yet been developed. Ethical parameters for human enhancement, or the use of data from brain activity, are similarly unregulated.

"Neurodata" is categorically different from the data normally accumulated by mobile or electronic devices, since they can allow the decoding of the user's mental activity. Scientific advances in the area are getting closer to decoding brain wave patterns that would identify voluntary movement signal patterns and pass them on to a robotic arm or leg[48]. But they could also identify other behavioural patterns, such as interests, emotions, prejudices, lies, personality disorders, among others.

The contributions of these advances to clinical diagnosis is evident, as is the adequacy of the bioethical framework to regulate these advancements. However, the application of neurotechnologies in other contexts (commercial, educational, police, and military purposes) is not subject to any technical or legislative regulations.

At the beginning of 2019, Israeli researcher, Moran Cerf, told the American magazine "Time", that he found neurotechnology to be the most frightening because of its potential to produce neural inequality in future society. Neural Inequality would mean that some people could become "disproportionately more intelligent" than the average[49]. This concern is not only expressed within journalistic and social forums, but is also a growing subject of scientific, ethical and legal studies [50],[51].

As a result of our increasing knowledge of the brain, the possibilities for inequitable access to enhancement, violations of patient and consumer freedom and autonomy, as well as commercial use of neurotechnology, have become emerging ethical questions. Their use for political, military, and policing purposes are also central elements of the debate.

Proposals from the science field

There is developing consensus in the world of ethics about the implications of neurotechnologies in society. Grouped under the umbrella of "neuroethics"[52], "neuro-rights" and other scientific initiatives (such as the one developed by Martha Farah in 2016[53], which proposed a series of basic concepts to develop an ethical debate on neurotechnologies), a common framework of ethical issues that require public policy action is taking shape.

One of the most advanced and supported proposals is that of the Morningside Group, a 27 member consortium of the most outstanding personalities in science and engineering, led by Rafael Yuste and Sara Goering. In 2017, this group proposed that brain-computer interfaces and artificial intelligence should respect and preserve four principles[54]:

- to protect privacy and personal autonomy
- to protect identity and agency (the latter understood in its sociological sense: the ability to choose our actions with free will)
- to regulate the "artificial augmentation" of brain capacities (which could produce inequalities)
- to control possible biases in algorithms or automated decision-making processes.

These four priorities aim at the responsible development of neurotechnologies, taking a similar approach to the regulation of genetic engineering and atomic energy.

Advances in law-making

Legal studies have highlighted similar areas in need of regulation. In 2018, Carlos Alberto Amoedo-Mouto summarized the legal landscape surrounding neurotechnology advancements in an article that identified two significant works to inform future regulation.

The first study is the manual *Law and Neuroscience*, from the Legislation and Neuroscience Research Network of the MacArthur Foundation, in USA, which proposes, as priority issues for legislators, the artificial enhancement of cognitive capacity, brain-computer interfaces and AI[55].

The second study is an analysis of comparative legislation in almost thirty countries[56], which recommends regulation of criminal liability; of expert use of neuroscientific advances; of access to the primary consumer brain level (neuromarketing and neuroeconomics); BCI's; and of brain death, and neuroscientific research standards, "especially of the frequent casual findings generated by experimental brain scanning".

Some countries already have regulatory standards, although they are few. France has incorporated into its Civil Code a modification to its bioethics legislation to regulate the use of brain information as expert evidence[57]. In Latin America, neuro-rights are still in the realm of the academic field [58], although there are examples of the use of neurotechnologies for legal evidence in countries such as Mexico.

In addition, the European Parliament, in 2017, approved the "Civil Law Standards on Robotics". This is one of the first concrete actions regarding regulation, in this case with specific recommendations to the European Commission[59].

Conclusions

Just as space research culminated in the conquest of space, and genome research culminated in the sequencing of the human genome, research on the brain is approaching the discovery of one of the final frontiers: the human brain.

In the same way that today we have space and genetic legislation with shared participants all over the world, we are on the threshold of developing a global regulatory framework for the responsible use of brain information and the preservation of human sanctity.

The regulation and definition of a legal framework for the development and use of novel neurotechnologies, far from being an obstacle, could be an opportunity for Chile to step up as an international leader on this issue. Such a deed may have historical importance for future society.

Disclaimer

Parliamentary Technical Advisory, is focused on supporting preferably the work of the Legislative Committees of both Chambers, with special attention to the follow-up of the bills. This is intended to contribute to legislative certainty and to reduce the gap in the availability of information and analysis between the Legislative and the Executive.

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