‹ technology radar ›

neurotechnologies

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neurotechnologies

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‹ about the series ›

The "Technology Radar" series is a periodic publication by the ANPD that aims to provide concise overviews of emerging technologies that will impact or are already impacting the national and international data protection landscape.

Without the intention of exhausting the topics or establishing institutional positions, the purpose of the series is to add relevant information to the debate on data protection in the country, with texts structured in a didactic and accessible way for the general public.

For each topic, the main concepts, potentialities, and future prospects are addressed, always with an emphasis on data protection in the Brazilian context. ▪

‹ translators’ note ›

The translation process of this text revealed the need to update certain formal aspects (citations and references). It was also necessary to update certain sources consulted, in order to ensure the accuracy of the data presented in the study. To this end, footnotes were inserted to clearly indicate the changes made to the content.

‹ list of abbreviations and acronyms ›

AEPD – Spanish Data Protection Agency
ANVISA – Brazilian Health Regulatory Agency
BRAINN – Brazilian Institute of Neuroscience and Neurotechnology
CONITEC – National Commission for the Incorporation of Technologies into the Unified Health System
CTI – Renato Archer Information Technology Center
DReANNs – Devices for Rehabilitation and Assistance in Neuroscience and Neurotechnologies
EDPS – European Data Protection Supervisor
EEG – Electroencephalography
fMRI – Functional Magnetic Resonance Imaging
fNIRS – Functional Near Infrared Spectroscopy
GPA – Global Privacy Assembly
ICO – Information Commissioner's Office
fMRI – Functional Magnetic Resonance Imaging
IIN-ELS – Edmond and Lily Safra International Institute of Neurosciences
INCT NeuroTec-R – National Institute of Science and Technology for Neurotechnology Responsible
ISD – Alberto Santos Dumont Institute for Teaching and Research
LGPD – Brazilian Data Protection Law
MEC – Ministry of Education
OECD – Organization for Economic Cooperation and Development
OAS – Organization of American States
UN – United Nations
PET-CT – Positron Emission Tomography
RIPD – Ibero-American Data Protection Network
SUS – Unified Health System
tDCS – Transcranial Direct Current Stimulation
tFUS – Transcranial Focused Ultrasound Stimulation
UFMG – Federal University of Minas Gerais
UNESCO – United Nations Educational, Scientific and Cultural Organization
UNICAMP – State University of Campinas
UNIFESP – Federal University of São Paulo

‹ summary ›

‹ introduction ›

Since the 2010s, interest in neurotechnologies has been growing, partly due to their integration with digital technologies and artificial intelligence (UNESCO, 2023, p. 33; Yuste, 2023). In academic circles, some argue that the significant advances in these new technologies have transformative impacts on research in the field of neuroscience (Vázquez-Guardado *et al.*, 2020) and their medical application for neurological and psychiatric treatments (UN, 2024, p. 21–23). Confirming this perspective, in 2023, news spread around the world that researchers at the Swiss Federal Institute of Technology had created a *"brain-spine interface"* device that enabled Gert-Jan Oskam, a man with total paralysis in his legs, to walk again (Gumbrecht; McPhillips, 2023). Neurotechnology creates a "digital bridge from the brain to the spine" (Lorach *et al.*, 2023, p. 126). When Oskam thinks about walking, cranial implants detect electrical activity in the cortex, the outer layer of the brain. This signal is transmitted and decoded by a computer he wears in a backpack, which then transmits the data to the spinal cord pulse generator (Lewis, 2023).

On the other hand, economic interests in the market are also driving neurotechnologies and their application in consumer market sectors such as education (Williamson, 2019). Recent estimates indicate that there is a market that could grow at an annual rate of 14.4%, from US$ 11.3 billion in 2021 to US$ 24.2 billion in 2027 (UNESCO, 2023, p. 18).

In addition to their industrial potential and their ability to promote scientific progress and human well-being, technologies that interact with the brain raise very important ethical and legal questions, notably due to the risks they pose to fundamental (human) rights such as the free development of personality, freedom of thought, privacy, bodily integrity, and non-discrimination. According to a report by the United Nations (UN) Human Rights Council, neurotechnologies affect fundamental (and human) rights in a unique way (UN, 2024, p. 18). For example, brain-computer interface (BCI) neurotechnologies, such as Functional Magnetic Resonance Imaging (fMRI) devices, and electroencephalography (EEG), instead of being used for medical diagnosis, can be employed by governments and private entities for surveillance and monitoring of individuals (Ienca; Jotterand; Elger, 2018, p. 270).

The topic has been the subject of intense academic and interdisciplinary debate[1] and has been addressed by the most relevant international forums, such as the UN (2024), the United Nations Educational, Scientific and Cultural Organization – UNESCO (2023), the Organization of American States – OAS (2023), and the Organization for Economic Cooperation and Development – OECD (2019).

Thinking about the governance and legal regulation of neurotechnologies is one of the developments of this global debate. There are at least three schools of thought on how these emerging technologies should be regulated, given the regulatory frameworks currently in place and the possible impacts and challenges imposed on human and fundamental rights. The first argues that new rights should be created to specifically protect the brain and mind: neuro-rights. It is considered that the current scope of protection of rights and freedoms is insufficient to provide adequate legal protection against the misuse of neurotechnologies. Neuro-rights include the following: the right to cognitive freedom, the right to mental privacy, the right to mental integrity, and the right to psychological continuity (Ienca; Andorno, 2017; Ligthart *et al.*, 2023, p. 4). The second school of thought, in turn, advocates that existing rights should be interpreted in an updated manner and adapted to the new socio-technical context, but that new rights are not necessary. Its advocates dispense with the creation of neuro-rights and understand that existing human and fundamental rights systems should be interpreted and applied in accordance with the social and technical reality of progressive development and adoption of neurotechnologies (Rainey *et al.*, 2020; Ligthart *et al.*, 2023, p. 4–5). Finally, the third line of thinking understands that it is unnecessary to reform legislation or changes of interpretation legal to deal with the neurotechnologies. Despite its current lack of prestige, the idea persists that existing law, as interpreted, is sufficient to address the challenges raised by neurotechnologies (Ligthart *et al.*, 2023, p. 5).

This study does not aim to analyze neuro-rights, but rather the repercussions of neurotechnologies in accordance with the personal data protection regime provided for in the Brazilian Data Protection Law

1 *The scientific output is voluminous, so we highlight the following works, among others: IENCA, M.; ANDORNO, R. Towards new human rights in the age of neuroscience and neurotechnology.* Life Sciences, Society and Policy, [S.l.], *v. 13, n. 1, p. 1–27, 2017; LIGTHART, S.* et al. *Minding Rights: Mapping Ethical and Legal Foundations of 'Neurorights'.* Cambridge Quarterly of Healthcare Ethics, [S.l.], *v. 32, n. 4, p. 461–481, 2023; SARLET, Gabrielle B. S.; SARLET, Ingo W.; WESCHENFELDER, Lucas R. Por uma gramática dos neurodireitos na perspectiva de uma efetiva proteção da pessoa humana no Brasil em face da complexidade, dos impactos e das externalidades negativas do emprego das neurotecnologias.* In*: PINTARELLI, Camila; PIOVESAN, Flávia; ABBOUD, Georges (Org.).* Constitucionalismo digital e direitos humanos*: desafios da internet, inteligência artificial e neurotecnologia. São Paulo: Thomson Reuters Brasil, 2024. p. 389–418.*

(LGPD). Although the scope of this Technology Radar focuses on the interpretation and application of Law No. 13709/2018 to the context of neurotechnologies, the National Data Protection Agency (ANPD) has not taken any position on the currents of thought described above. Since neurotechnologies are fundamentally anchored in the processing of neural data, the overall objective of this study is to understand the landscape of neurotechnologies and their implications for personal data protection in Brazil.

Another noteworthy methodological limitation is that the study does not aim to conduct an in-depth analysis of concepts discussed by different fields of knowledge, such as consciousness, subconsciousness, personal identity, etc. Although these are highly relevant topics for understanding emerging technologies capable of interacting with the human brain, they are not included in the scope of this technology radar.

In addition to the current relevance and scientific importance of this emerging technology, this study is justified by the actions of other data protection authorities and institutions around the world: Information Commissioner's Office – ICO (2023); European Data Protection Supervisor – EDPS (2024); Agencia Española de Protección de Datos – AEPD (2024); Red Iberoamericana de Protección de Datos – RIPD (2023); and Global Privacy Assembly – GPA (2024).

‹ key concepts ›

As a new frontier in technology and human knowledge, neurotechnology arises from the intersection of several disciplines, including neuroscience, chemistry, bioengineering, computer science, materials science, and medical technology (UNESCO, 2023). Given the novelty and complexity of the subject, it is necessary to clarify two concepts whose understanding is essential for this study on neurotechnologies in light of personal data protection, namely: neurotechnologies and neural data.

Neurotechnologies

The OECD (2019, p. 6) defines neurotechnologies as "devices and procedures used to access, monitor, investigate, assess, manipulate, and/or emulate the structure and function of the neural systems of natural persons". The same concept is adopted by International Bioethics Committee of Unesco (2022, p. 13), which incorporates into its definition of neurotechnologies the actions of devices and procedures on the neural systems of animals.

Neurotechnologies refer to a range of methods and tools for interacting with the brain and nervous system, and this interaction may occur passively, to monitor brain activity, or actively, to alter it (Andorno, 2023, p. 12). In turn, the ICO (2023, p. 8) conceptualizes neurotechnologies as "consumer, enterprise and healthcare devices and procedures, both invasive and non-invasive, that directly record and process neurodata for the purposes of gathering data, controlling interfaces or devices, or modulating neural activity".

The UN (2024, p. 2), through a report by the Human Rights Council Advisory Committee, highlights that "the term 'neurotechnologies' encompasses an array of devices and systems that interact with the central nervous system through electrical, magnetic, optogenetic[2] and other means". Such devices can aid in understanding how the brain functions, or they can even intervene in nervous system processes with the aim of restoring functions or enhancing capabilities (UN, 2024, p. 2).

2 *Optogenetics uses genetic engineering to make biological tissues sensitive to light (Krueger* et al.*, 2012).*

For Bertoni and Ienca (2024, p. 2), neurotechnology should be understood as a broad concept that encompasses "[…] devices, tools, systems, and algorithms used to understand, and/or influence, access, monitor, assess, emulate, simulate, or modulate the structure, activity, and function of the nervous systems of human beings and other animals". This definition, compared to the others above, is more specific and comprehensive in terms of the purpose of neurotechnology use, as well as incorporating algorithms as an integral part of the neurotechnology spectrum.

Neurotechnologies enable the establishment of a direct connection between the brain and external devices, which gives them a unique characteristic that requires attention to ethical and legal repercussions, since this type of connection can allow interventions in brain activities (UN, 2024, p. 2). The UN (2024, p. 2–3) justifies these specificities based on what neurotechnologies usually provide, given that they:

> *[…] (a) enable the exposition of cognitive processes; (b) enable the direct alteration of a person's mental processes and thoughts; (c) bypass the individual's conscious control or awareness; (d) enable non-consensual external access to thoughts, emotions and mental states; (e) are nurtured by "neurodata", which are needed for their own functioning, calibration and optimization; and (f) collect, analyse and process large personal datasets of a highly sensitive nature.*

Two types of technical tools are included in neurotechnologies: those that measure and examine chemical and electrical signals from the brain or limb nerves; and those that interact with the nervous system (UNESCO, 2022, p. 13). According to UNESCO (2022, p. 13), technical measurement and analysis tools "[…] may be used to identify the properties of nervous system activity, understand how the brain works, diagnose pathological conditions, or control external devices (neuroprostheses, 'brain-machine interfaces') […]". On the other hand, the technical tools for interacting with the nervous systems to alter its activity techniques for interacting with the nervous system to alter its activity may be used to restore sensory input, such as those aimed at restoring hearing or stopping tremors (UNESCO, 2022, p. 13).

Aiming to improve the health and well-being of individuals, neurotechnologies and their devices can replace part of the body as well as stimulate or inhibit brain activity (UNESCO, 2022, p. 19). One of the types of neurotechnologies highlighted by UNESCO (2022, p. 20) is brain-computer interfaces, which aim to translate brain activity into an expected result, such as moving a prosthesis or improving the mood of a depressed individual. In this sense, "neurodevices incorporate data on the abnormal state to be corrected as well as data on the state of normality to be obtained [...]" (UNESCO, 2022, p. 34). The benchmark for the normal state is the activity observed in healthy brains (UNESCO, 2022, p. 34).

The UN (2024, p. 3) defines the brain-computer interface as an emerging category of neurotechnologies, in which devices and methods are connected directly to the brain, enabling communication between the brain and the devices. In this category, neural activity is collected through a recording device and decoded to obtain information from the individual, which is used to control external devices, establishing a closed loop interaction in this process (UN, 2024, p. 3).

According to the ICO (2023, p. 10), neurotechnologies can be invasive, semi-invasive, or non-invasive. Invasive technologies are those implanted through surgical intervention, allowing direct contact with the brain and providing accurate information on brain patterns (ICO, 2023, p. 10). Semi-invasive neurotechnologies focus on inserting devices into the meningeal membranes (ICO, 2023, p. 10). Non-invasive neurotechnologies, in turn, can be placed inside or outside the body, collecting less detailed data and allowing for less complex inferences from such data, according to the ICO (2023, p. 10). Although considered non-invasive, these devices can interact with the brain in a fairly direct manner (ICO, 2023, p. 10). It should be noted that this classification is not consensual. The EDPS and the AEPD (2024, p. 2), for example, also consider devices implanted near the brain to be invasive. With regard to non-invasive technologies, they understand that this category only covers neurotechnologies that are placed outside the body. In the medical field, the distinction between neurotechnologies is based on their invasiveness (UN, 2024, p. 3). Invasive technologies are more accurate and powerful, but also involve greater risk, as they require surgical intervention to introduce devices (UN, 2024, p. 3). Non-invasive technologies, on the other hand, are used externally, without the need for penetration into the body, as in the case of helmets, wristbands, and earphones (UN, 2024, p. 3).

On this subject, the EDPS and the AEPD (2024, p. 2) mention that the way neurotechnologies are constructed and interact with the nervous system determines their subfields. The construction of these technologies relates to whether they are invasive or not. Interaction, in turn, refers to the recording or manipulation of brain activity. The recording of brain activity can be carried out through technologies such as EEG or fMRI, while the manipulation of brain activity can occur through the modulation of this activity, generating short-term effects, as in the use of neurostimulation[3], or long-term effects, as in the use of neuromodulation[4] (EDPS; AEPD, 2024, p. 3). In order to better systematize the forms of classification of neurotechnologies, we present Table 1.

Another way to classify neurotechnologies is to distinguish between those that record and analyze data from the nervous system and those that stimulate and modulate neural patterns, with invasive and non-invasive technologies being considered as read devices, or read-write devices (ICO, 2023, p. 10). Devices such as EEG or fMRI are considered by the ICO (2023, p. 10) as read devices, while neurostimulation and neuromodulation tools are classified as read-write devices. The British data protection authority warns that "the ability to modulate brain activity can apply to both invasive and non-invasive technologies and may significantly increase the risk of processing personal information […]" (ICO, 2023, p. 10). The risks involving neurotechnologies and the processing of personal data will be discussed in greater detail in the section Neurotechnologies and the protection of personal data.

3 *Neurostimulation, or electrical stimulation, is the "[…] direct administration of electrical pulses to nervous tissue to modulate a pathologic substrate and to achieve a therapeutic effect […]" (Boon* et al.*, 2007, p. 1551). It is a treatment widely used for neuropsychiatric disorders (Vonk; Herdt; Sprengers; Ben-Menachem, 2012, p. 955).*

4 *The neuromodulation modifies the neurological function through the use of electrical, magnetic, or chemical (pharmacological) stimuli to specific targets (North* et al.*, 2022, p. 1054). The technology consists of the application of electrodes to the brain, spinal cord, and peripheral nerves, so that the devices connected to the power generator deliver a low-voltage current to the nerve in order to inhibit pain signals or stimulate neural impulses where they did not previously exist (International Neuromodulation Society, 2023). Although commonly associated with chronic pain relief, neuromodulation has a broad therapeutic scope and can be applied, for example, to the treatment of movement disorders, epilepsy and psychiatric disorders (International Neuromodulation Society, 2021, 2023).*

Table 1 *Classification of neurotechnologies*

Criterion	Category	Application	Examples
Interaction	Passive	Recording of brain activity	EEG and fMRI
	Active	Manipulation of brain activity	Transcranial Magnetic Stimulation and Deep Brain Stimulation
Receptor construction/ location	Invasive	Involves physical intervention in the human body	Brain implants and cochlear implants
	Semi-invasive	Placement of devices in the meningeal membranes	Sphenoidal electrode
	Non-invasive	Does not require direct interven-tion in the human body	EEG and Transcranial Magnetic Stimulation

Source: Adapted from ICO (2023) and EDPS and AEPD (2024).

Neural data

The use of neurotechnologies to improve health or enhance capacities involves the processing of data from individuals' brains and nervous systems. As will be discussed below, there is no uniformity in the nomenclature used to designate such data, which is referred to by scholars and international institutions as personal brain data, neural data or neurodata.

Personal brain data, according to the OECD (2019, p. 6), is "[…] data relating to the functioning or structure of the human brain of an identified or identifiable individual that includes unique information about their physiology, health, or mental states". Neurodata, according to the ICO (2023, p. 8), is "first order data gathered directly from a person's neural systems (inclusive of both the brain and nervous systems) and second order inferences based directly upon this data".

The EDPS and the AEPD (2024, p. 4) define neurodata, in turn, "[…] as the information gathered from the brain and/or from the nervous system". The inferences obtained from this data are also considered by the EDPS and the AEPD (2024, p. 4) as neurodata.

The collection of this type of data can be carried out passively, when the individual is not required to perform any type of activity for the processing to occur, and actively, when neurotechnologies collect data while the individual is performing a specific activity (EDPS; AEPD, 2024, p. 3). In terms of content, neurodata may relate to the structure, function, and activity of the brain, as well as the peripheral nervous system (EDPS; AEPD, 2024, p. 5–6).

Bertoni and Ienca (2024, p. 2) refer to data collected by neural interfaces as neural data. The authors emphasize that neural data is quantitative in nature and concerns the composition, activity, and function of the nervous systems of living organisms. They add that such data is dynamic in nature and subject to constant change due to the brain's inherent neuroplasticity[5] (Bertoni; Ienca, 2024, p. 6). It is important to highlight that, in the context of processing activities data, neural data can be combined with other (non-neural) data to aid in understanding human mental states[6] and processes (Bertoni; Ienca, 2024, p. 5–6; Ienca; Malgieri, 2022, p. 3–4). Digital phenotyping[7] illustrates the possibility of integrating neural and non-neural data to infer information and knowledge about mental states – such as cognitive variations useful for the diagnosis and treatment of disorders such as schizophrenia. This is a field of research that uses data obtained from the everyday use of digital devices for example, typing and screen scrolling patterns, voice and ambient sounds) to measure or offer relevant proxies of human behavior and functions (Huckvale; Venkatesh; Christensen, 2019), including neurocognitive functions. In addition, artificial intelligence systems and machine learning techniques have been applied both in digital phenotyping (Huckvale; Venkatesh; Christensen, 2019; Jean; Guay Hottin; Orban, 2025), as well as in approaches aimed at recognizing affective or emotional states, through the processing of data such as facial expressions, voice and speech, and even tracking of eyelid movement and gaze. (Khare *et al*., 2024; Li; Xu; Feng, 2021; Skaramagkas *et al*., 2023).

5 *Neuroplasticity, in general terms, refers to the brain's ability to change (Innocenti, 2022).*

6 *Mental states are "[…] any conglomeration of mental representations and propositional attitudes that corresponds to the experience of thinking, remembering, planning, perceiving, and feeling" (Ienca; Malgieri, 2022, p. 4). More didactically, Oosterwijk* et al. *(2012, p. 1–2) teach that the human mind consists of a variety of successive mental states throughout life, which are commonly understood as emotions "[…] (e.g., fear, disgust, love), cognitions (e.g., retrieving a memory, planning the future, concentrating on a task), perceptions (e.g., face perception, color perception, sound perception), and so on".*

7 *According to Huckvale, Venkatesh, and Christensen (2019, p. 1), based on Torous* et al. *(2016), Mohr, Zhang, and Schueller (2017), and Onnela and Rauch (2016), "digital phenotyping (or personal sensing) is the moment-bymoment, in situ quantification of the individual-level human phenotype using data from personal digital devices. It seeks to exploit the potential of data that are automatically generated and aggregated ›*

In this sense, neural data contributes to the generation of what Ienca and Malgieri (2022, p. 4) call mental data, defined as "[…] any data that can be organized and processed to infer the mental states of a person, including their cognitive, affective, and conative states" (Ienca; Malgieri, 2022, p. 4). As demonstrated, both neural and non-neural data can be used to infer mental states and processes (Ienca; Malgieri, 2022, p. 7). On the other hand, it is also possible to extract information about the structure and functioning of the brain from neural data that does not necessarily reveal these mental aspects. For this reason, as the authors point out (Ienca; Malgieri, 2022, p. 7), mental data is not necessarily neural data, and the reverse is also true[8].

From this brief review of the concepts of neurotechnology and neural data, we understand that neurotechnologies can be defined as the set of devices and methods that interact with the human and animal brains and nervous system, aiming to access, record, process, evaluate, monitor, simulate, or modulate the activity and functions of these systems. These forms of interaction, which may or may not be invasive, occur through the capture and processing of neural data. Despite the different nomenclatures that designate the data captured and processed by neurotechnologies, we have opted for the term "neural data" due to its analogous composition to other types of data, such as biometric data and synthetic data. In this sense, we define neural data as data collected from the brain and related to the composition, activity, and functioning of the human nervous system and the inferences obtained from this data.

‹ applications and potential uses of neurotechnologies ›

Neurotechnologies have a wide range of applications, and their potential uses are constantly expanding. For example, the cognitive, sensory, and motor abilities of patients with neurological disorders can be improved through the use of these technologies, which can also be used by healthy individuals to enhance their physical or cognitive abilities (UNESCO, 2022,

› by smartphones, wearables and other connected devices to measure (or offer robust proxies for) human behavior and function in both health and disease. Today, these data streams include sensor measurements, activity logs and usergenerated content".

8 *The concept of mental data is close to the notion of cognitive biometric data, advocated by Magee, Ienca, and Farahany (2024) and complemented by UNESCO (2024), as will be seen in Section "Is neural data personal data?".*

p. 15). In the field of early childhood education, countries such as China are already using neurotechnologies to measure student performance. In Jinhua Xiaoshun, students wear a head-mounted device that measures the electrical signals of neurons and translates them into an attention score using an algorithmic system. The more focused the student is, the higher the score (Wang; Hong; Tai, 2019).

The use of neurotechnologies in the medical sector includes the adoption of both invasive and non-invasive technologies. Examples of invasive medical techniques and devices mentioned in the literature include: (i) direct brain stimulation used to treat nervous system disorders such as epilepsy; (ii) neuroprostheses, such as retinal implants or spinal implants (ICO, 2023, p. 12); (iii) cochlear implants; (iv) "[…] deep brain stimulators which can help people with Parkinson's disease"; (v) brain implants that help people without body parts or with "[…] damaged limbs to feel heat and cold through their prostheses"; (v) brain implants for individuals with Amyotrophic Lateral Sclerosis (ALS) that allow them to communicate fluently, as well as write and send emails (Yuste; Genser; Herrmann, 2021, p. 156).

Neurotechnologies for assistive communication, such as those needed for speech translation and neuromodulation for the treatment of people dealing with addiction or who have complex psychological needs, are also examples of their use in healthcare sector (ICO, 2023, p. 13).

Beyond the medical sector, wearable neural devices, which can be marketed as wellness and fitness monitors, are a type of non-invasive neurotechnology that can allow the extraction of health insights from the people who use them, even though they did not initially have this function (ICO, 2023).

An assessment of 30 companies that offer products on the consumer market (notably from the United States) showed that the products analyzed use technologies originally applied in the medical field for the processing of data through EEG graphical imaging, infrared (fNIRS[9]), and transcranial direct current stimulation (tDCS[10]) . These products are intended for wellness, leisure/entertainment, and research. Products aimed at promoting well-ness, include applications for improving sleep quality, relaxation and focus, combating symptoms of depression and improving mental health,

9 *Functional Near Infrared Spectroscopy (fNIRS) is a non-invasive neuroimaging technique that uses near-infrared light to measure brain activity.*

10 *A Transcranial Direct Current Stimulation (tDCS) is a non-invasive brain stimulation technique that uses low-intensity electrical current to modulate neuronal activity.*

reducing stress, enhancing work performance, and maximizing cognitive functions (Genser; Damianos; Yuste, 2024, p. 23–29).

The EDPS and AEPD (2024) define three categories for neural data processing, based on their intended purpose. In this sense, the following are considered: (i) processing that aims to provide direct information or predictions about people's health or fitness and about basic psychological processes; (ii) processing that enables the control of an application or device; (iii) and processing that enables the stimulation or modulation of a person, obtaining neurofeedback in this process (EDPS; AEPD, 2024, p. 6–8).

Examples of application domains for data processing aimed at providing direct information or predictions about people's health or fitness and basic psychological processes include: (i) the medical field, to understand the brain and the neural system; (ii) education, to improve performance and learning; (iii) entertainment, to increase satisfaction in the use of leisure and entertainment equipment; (iv) economics and marketing, to understand and anticipate consumer behavior; (v) the workplace, to monitor workers in order to understand and improve their performance, as well as to assist in recruitment and promotion; (vi) safety and surveillance, to monitoring with a view to preventing accidents or crimes (EDPS: AEPD, 2024, p. 6–7). In this context, artificial intelligence has been used to understand patterns that allow brain activity to be translated (EDPS; AEPD, 2024, p. 6).

Within the scope of processing that enables the control of an application or device, the application domains are: (i) prostheses, implants, or other types of assistance to aid in health conditions and daily activities; (ii) games and virtual reality for the control of video games and software; (iii) robotics for the control of devices or applications that do not use hand control; (iv) and defense, for the control of weapons, vehicles, and drones (EDPS; AEPD, 2024, p. 7–8).

In the category of processing that makes it possible to stimulate or modulate a person, obtaining neurofeedback in the process, the EDPS and AEPD (2024, p. 8) present the following application domains: i) psychology, which uses neural data processing to alter the way the brain reacts to stimuli, monitoring its activity and obtaining feedback; (ii) and neuroenhancement, which seeks to improve the cognitive and affective abilities of healthy people.

Artificial intelligence and machine learning expand the use of neurotechnologies, acting in the processing and analysis of neural data sets (UN, 2024, p. 3). In agreement, the EDPS and the AEPD (2024, p. 14) point out that artificial intelligence can provide a significant increase in the insights extracted from neural data in conjunction with other (non-neural) data.

While the development of neurotechnologies brings with it significant advances in improving individuals' health conditions, it also poses new challenges, particularly with regard to the protection of personal data.

‹ neurotechnologies and personal data protection ›

Having defined the contours of the concepts of neurotechnologies and neural data, and presented an overview of the applications and potential uses of these emerging technologies, it is necessary to analyze both the concepts and their applications from the perspective of personal data protection, considering in particular the legal regime provided for in the LGPD. This analysis does not seek to exhaust the subject but offers an initial approach to verify the application of the general rules of the LGPD to the processing of neural data and its main repercussions.

Is neural data personal data?

In the LGPD, as well as in the Brazilian legal system, there is no legal definition of neural data[11]. In the United States, on the other hand, some states, such as California and Colorado[12], have specific legal treatment of the subject. However, even though there is no express legal provision on the matter, data protection regulations in Brazil apply to the processing of neural data.

11 *There are a several legislative proposals pending in the National Congress to address this issue. Some examples that can be mentioned are: (i) Bill No. 1229/2021 to reform the LGPD, which, besides proposing a definition of neural data, presents specific rules for the processing it; (ii) Bill No. 522/2022, which seeks to amend Article 11 of the LGPD by introducing a paragraph with the concept of neural data; (iii) Bill No. 2174/2023, which provides for "principles for the protection of fundamental rights related to the human brain and nervous system, with the aim of ensuring the protection and promotion of individuals' neuro-rights"; and (iv) the Draft Reform of the Civil Code presented to the Federal Senate, which provides, in the chapter on "Digital Civil Law," on mental privacy and "brain data."*

12 *The California Privacy Rights Act of 2020 and the Colorado Privacy Act of 2021 wererecently amended to include provisions on neural data and neurotechnologies.*

A fundamental point for the material scope of the LGPD and, consequently, for the application of its legal regime, is that personal data is the subject of processing activity. That is, Brazilian data protection law does not apply unless the data is processed as a personal data. Therefore, the concept of personal data defines the limits of the application of data protection legislation (Machado, 2023, p. 24; Bygrave; Tosoni, 2020, p. 105). This raises the first relevant question for the analysis of neurotechnologies from the perspective of personal data protection: is the neural data processed by these emerging technologies personal data according to Article 5, I, of the LGPD?

Under the law, personal data is "information regarding an identified or identifiable natural person" (Article 5, I, of the LGPD). According to the broad concept adopted in the Brazilian system (ANPD, 2023a; ANPD, 2024), the concept of personal data includes not only CPF[13], but also data that, with reasonable effort and means, can identify someone using auxiliary data (e.g., data publicly available on the internet). The broad scope of the concept definitely includes neural data (Hallinan *et al.*, 2014, p. 63).

In the context of neural data processing, the accurate identification of a natural person ("identified natural person") can be done by either the data subject themselves – in the context of virtual reality games, for example, the processed neural data is linked to the registration data provided by the player themselves[14] – or the processing agent – such as in the case of a medical diagnostic examination (EDPS; AEPD, 2024, p. 4). In addition, there are situations in which, although the natural person is not accurately individualized, there is significant potential for identification, i.e., the natural person is identifiable. According to UNESCO's International Bioethics Committee, anonymizing neural data can be an overly complex task, as "a large body of evidence indicates that a data signal cannot be divorced from the identity that produced that signal." (UNESCO, 2022, p. 48). In fact, studies demonstrate the possibility of re-identifying individuals and predicting future emotional states and behaviors through neural data, such as electrophysiological measurements, neuroimaging, and neural activity (Ienca *et al.*, 2022, p. 6; Schwarz *et al.*, 2019).

Advances in neuroscience – more specifically in the field of brain connectomics[15] – point to the possibility of using neural data to single out

13 *In Brazil, the CPF number is equivalent to the individual taxpayer identification number in other countries.*

14 *Even if self-identification is followed by actions taken by the treatment agent to verify age, for example, there is no de-characterization of identification by one's own actions.*

15 *The term 'connectomics' defines a new field of neuroscience that aims to map the structural and functional networks through which the brain is interconnected, employing cross-sectional imaging techniques and characterizing the properties of these networks using theoretical graphical approaches" (Cocchi; Zalesky; Fontenelle, 2012, p. 131).*

individuals based on their "brain fingerprints". This concept was proposed in 2015 by Finn *et al.* in research on the functional connectome[16]. In the study, the researchers demonstrated that the identification procedure based on functional neuronal interactions can be conducted with a high success rate (Finn *et al.*, 2015). Thus, the statement that "an individual's functional brain connectivity profile is both unique and reliable, similar to a fingerprint, and it is possible, with near-perfect accuracy in many cases, to identify an individual among a large group of subjects solely on the basis of her or his connectivity profile" (Van de Ville *et al.*, 2021, p. 1). Other approaches also indicate that electroencephalogram neural data is capable of uniquely identifying someone (Yang; Deravi, 2017).

It is also important to note that, in addition to neural data being categorised as personal data – whether provided or observed[17] – it is also data from which other personal information can be inferred[18]. This means that mental states and neurophysiological conditions inferred from the processing of data on the structure or functioning of the brain are also personal data. In fact, this inferred data can be considered second-order neural data (ICO, 2023, p. 8).

Once the classification of neural data as personal data has been confirmed, another relevant question to address is: can neural data be considered sensitive personal data? The LGPD defines sensitive personal data as "personal data concerning racial or ethnic origin, religious belief, political opinion, affiliation to trade unions or to a religious, philosophical or political organization, data regarding health or sex life, genetic or biometric data, when related to a natural person". (Art. 5, II, of the LGPD). Although the legal text does not mention data on brain structure and function, in many situations neural data, in the context of processing activities, will reveal sensitive information (EDPS; AEPD, 2024, p. 15; Rainey *et al.*, 2021, p. 145–146).

Consider, for example, health data. This type of sensitive data can be understood as personal data related to the physical or mental health of a natural person, including the provision of health services, which reveal information about their health status (EU, 2016; Teffé, 2022). Furthermore, health data is understood as data which reveals information relating

16 *Connectome is defined as "a comprehensive structural description of the network of elements and connections forming the human brain" (Sporns; Tononi; Kötter, 2005, p. 245). According to Sporns (2011, p. 110, our translation), the human connectome should be understood in terms of structural and functional connectivity: "[…] the connectome is primarily concerned with structure, the extensive but finite set of physical connections between neural elements. The physical reality physical of structural connectivity provides an important point of methodological convergence – different empirical methods for mapping structural connections should ultimately provide a consistent anatomical description. In comparison, functional connectivity, which unfolds within the structural network, is significantly more variable over time, reflecting changes in internal state or neural responses to stimuli or task demands.*

17 *Data provided is data that originates directly from the data subject's voluntary and conscious action, while the observed data constitutes data that is the object of observation by third parties and captured in digital format (EC, 2016, p. 12; Machado, 2023, p. 16–17).*

18 *Derived data and inferred data are data resulting from other personal or ›* to the past, current or future physical or mental heatlh[19]. The concept achieves neural data that reveals current, past, or future potential neurological diseases (Ienca; Malgieri, 2022, p. 9–10), such as Parkinson's disease (Conti *et al.*, 2022) and depression (Mitra *et al.*, 2023).

As highlighted by Ienca *et al.* (2022), even without decoding mental information, new inferential models based on neural data are capable of making inferences about current and future brain function or health status. These inferences and predictions, including early signs of cognitive decline, can be made about both individuals and groups.

In addition to health data, the processing of neural data can also reveal other sensitive information. Specialized literature contains studies that (i) relate functional connectivity analysis using fMRI to political-ideological positioning (Yang *et al.*, 2022); and (ii) support the feasibility of using electroencephalogram signals for biometric purposes (Yang; Deravi, 2017). However, contextual analysis will always be necessary, since neural data will not always imply the inference of sensitive personal data. For example, this is likely to be the case for applications that process data on emotions using non-biometric techniques (Ienca; Malgieri, 2022, p. 10).

Currently, there are proposals for legislative change and legal understanding in order to apply the most rigorous and protective regime for sensitive data to the processing of neural data. In Brazil, Bill No. 522/2022 was introduced in the Chamber of Deputies to amend the LGPD and provide regulatory discipline for neural data, including classifying it as sensitive personal data. On the other hand, at the international level, the preliminary version of the "Recommendation on the Ethics of Neurotechnology", published in April 2024[20], not only refers to neural data and *biometric cognitive data* as particularly sensitive (UNESCO, 2024), but also recommends revisiting existing laws to ensure robust protection for such data. Biometric cognitive data – as defined by Magee, Ienca, and Farahany (2024) – comprises neural data itself, as well as other data collected by biometric technologies or biosensors that can be processed to infer mental states (UNESCO, 2024).

› non-personal data, respectively, due to reasoning or non-probabilistic logical-mathematical operations and the application of complex statistical models based on data mining algorithms and machine learning systems (Machado, 2023, p. 17; OECD, 2014, p. 5; EC, 2018, p. 9).

19 *Recital 35 of the EU General Data Protection Regulation (EU, 2016).*

20 *It should be noted that the original text was written in reference to the preliminary version of the Recommendation on the Ethics of Neurotechnology, published in 2024. However, the final version of the document was published in November of 2025, during the translation process.*

Neural data and data protection principles

Neural data is personal data, and its processing using neurotechnologies is subject to the personal data protection regime of the LGPD. As a result, data protection principles apply to data processing activities carried out using these emerging technologies. Although applicable, it is important to recognize that the novelty and risks of complete disclosure and intervention in the most intimate frontier of human beings – their minds, thoughts, and identities – pose challenges to such legal norms.

a) Principles of purpose, adequacy, and necessity

The principle of purposefulness establishes that the processing of personal data must be carried out in accordance with legitimate, explicit and specific purposes which must be communicated to the data subject at the time of the personal data processing operation (Article 6, I, of the LGPD). In addition, the principle of adequacy (Article 6, II, of the LGPD) determines that the lawfulness of the processing operation depends on its compatibility with the legitimate, specific, and explicitly informed purpose(s) to the data subject, taking into account the context in which the processing is carried out. Emerging neurotechnologies create challenges for both principles.

According to Ienca *et al*. (2022, p. 6), "the exact specification of purposes is very difficult for brain data, as current technology cannot preventively discern data from specific purposes from the myriads of brain signals." The difficulty of specifying the purposes of processing (collection, for example) in advance also has repercussions on the assessment of the compatibility of subsequent and secondary uses of neural data. Another challenge arises from the possibility that neurotechnologies may process data without the data subjects even being aware of such operations on their cognitive activities and neural signals (Ienca *et al.*, 2022, p. 6; Rainey *et al.*, 2020, p. 11).

There is also a point of tension regarding the principle of necessity. The need to process information requires a preliminary assessment to verify whether the specific purpose can be achieved with minimum use of personal data or with methods capable of reducing or eliminating its identifiers (ANPD, 2023a, p. 10; ANPD, 2023c, p. 25). Given the growing availability of neural data, including beyond medical and academic research uses, and integration with artificial intelligence systems, the ability to assess the need for processing may be compromised (EDPS; AEPD, 2024).

b) Principle of data quality

The standard aims to ensure the accuracy, clarity, updating, and relevance of personal data according to the necessity and for achieving the purpose of its processing (Art. 6, V, of the LGPD). In other words, processing agents have a duty to ensure that data subjects are not misrepresented, so that the data being processed is accurate, up-to-date, and relevant to the context of processing for as long as this activity continues.

In addition to the possibility that neurotechnologies (non-invasive, for example) may incur inaccuracies during the neural data collection process (Hallinan *et al.*, 2014, p. 67), one of the main reasons for concerns about these data in relation to the principle of data quality is neuroplasticity, or brain plasticity (EDPS; AEPD, 2024, p. 16). Research indicates that the brain structure changes over time and that brain development and function are influenced by different environmental events, such as sensory stimuli, psychoactive drugs, gonadal hormones, parent-child relationships, peer relationships, early stress, gut flora, and diet (Kolb; Mychasiuky; Gibb, 2014). Such changes in the brain most likely have repercussions on the updating and relevance of neural data for medical treatments, a problem that can certainly also extend to the eventual commercial uses of neural data.

For that matter, the EDPS and the AEPD draw attention to the discussion surrounding the reliability of inferences based on neural data, especially in relation to the way in which such data is processed, which may encounter problems with the suitability of statical methods used and the reproducibility of neuroscience findings (EDPS; AEPD, 2024, p. 17). Furthermore, considering the relevant limitations that may affect the accuracy (and possibility) of predictions based on artificial intelligence (Narayanan; Kapoor, 2024, p. 97–98), the care in its use in neurotechnology applications is crucial, given the risk of significant repercussions on decision-making about the health and lives of data subjects, as is the case with uses for predicting brain age (Heinrichs, 2023).

c) Principle of transparency

The principle of transparency guarantees data subjects clear, accurate, and easily accessible information about the processing of their personal data and the respective processing agents (Art. 6, VI, of the LGPD). The precept relates to the information provided to the data subject before processing begins, the information that must be easily accessible to them during processing, but also the information provided following a request for access to their own data (Council of Europe, 2018).

Because of the collection and processing of neural data can occur independently of the conscious will of the data subject, coupled with the high complexity of both the functioning of emerging technologies and the neural data and inferable information themselves, significant challenges are posed to the principle of transparency (EDPS; AEPD, 2024). However, in the field of neurotechnologies, which are increasingly integrated with algorithmic systems, transparency measures are necessary at different levels of neural data processing:

> *At the procedural levels, organizations collecting and using neural data should provide clear and accessible information about their practices. This includes detailing how data is collected, stored, used, and shared, as well as the purposes of data collection and any potential risks involved. At the algorithmic level, transparency involves explaining how algorithms process neural data, including the methodologies and assumptions underlying these algorithms. Organizations should disclose how neural data is analyzed and interpreted, ensuring that users understand the logic and potential biases in the algorithms. (Bertoni, Ienca, 2024, p. 9)*

d) Principle of non-discrimination

According to Article 6, IX, of the LGPD, the processing of data for unlawful or abusive discriminatory purposes is prohibited. This prohibition extends to the processing of neural data that constitutes unlawful discrimination. The term "neurodiscrimination" (Ienca; Ignatiadis, 2020, p. 83) has been coined to designate discrimination that " occurs when individuals or population groups are unfairly disadvantaged by inferences made from neurodata and/or biases in their collection and processing. " (Regulatory Horizons Council, 2022, p. 59).

The combination of neurotechnologies with approaches based on artificial intelligence, in addition to opportunities in the fields of scientific research and medical practice, raises risks of unlawful discrimination. Given the types of neural data being processed, such as estimates of emotional states, efficiency, and engagement in the workplace or school environment, and information about mental health (ICO, 2023), and the potential biases that, when introduced into data collection and training of artificial intelligence models, lead to accuracy problems (Ienca; Ignatiadis, 2020), the adoption of neurotechnology applications in practice is already and will continue to be associated with significant risks of discriminatory treatment (EDPS; AEPD, 2024).

In the insurance sector, for example, profiles or neuro-patterns can be used to discriminate against people based on their neurocognitive signals (e.g., signs of cognitive decline or progressive neurodegenerative disease) and consequent decision-making about insurance coverage or premium pricing (ICO, 2023, p. 19; Regulatory Horizons Council, 2022, p. 59; UN, 2024, p. 7). In the workplace, employees may be treated based on inferences about mental and emotional states or even physical or mental conditions unknown to the data subject or not previously diagnosed (ICO, 2023, p. 19).

e) Principle of security

The specialized literature highlights that information security should be, if not the main, one of the main concerns of neurotechnology developers

(Ienca; Haselager; Emanuel, 2018). Unauthorized access or compromise of the integrity of neural data, which are closely related to the intimate frontier of human thought and brain activity, are examples of security incidents that can result in serious consequences and damage to data subjects.

Among the possible incidents documented by researchers, we can mention a few. *Misleading stimuli attacks*, such as subliminal attacks on users of EEG-based brain-computer interfaces, enable the inference of individuals' personal data from the detection of brain responses to subliminal stimulation, that is, without the victims even being aware of this operation (Frank *et al.*, 2017). Invasive neuromodulatory devices are subject to the risk of *"brainjacking"*[21]. Once a malicious attacker gains control of the intracranial device, a variety of attacks can be carried out to cause different types of damage and violations of the legally protected rights and interests of data subjects, notably the rights to privacy, personal data protection, and health (Pycroft *et al.*, 2016; López Bernal *et al.*, 2020).

As a consequence the use of technical and administrative measures able to protect neural data from unauthorized access and accidental or unlawful situations of destruction, loss, alteration, communication, or dissemination, as determined by Article 6, VII, of the LGPD, is crucial for the development and implementation of neurotechnologies in Brazil. It is important to emphasize that processing agents must comply with the regulatory requirement of *data protection by design*[22], adopting technical measures – data encryption, differential privacy, among others – and administrative measures appropriate to the security of neural data from the design or initial stages of the product project (Yuste, 2023).

Legal hypotheses for the processing of neural data

Once the purpose for the processing of neural data has been specified – despite the difficulties pointed out above (Item 'a' of the Neural Data and Data Protection Principles section) – and if such data is necessary to fulfill that purpose, for the processing of neural data to be lawful, the processing operations must be supported by appropriate normative circumstances, in accordance with the provisions of Articles 7 and 11 of the LGPD. These legal grounds include the consent of the data subject,

21 *The term refers to unauthorized control of an intracranial electronic devices (Pycroft* et al.*, 2016).*

22 *Art. 46, § 2, of the LGPD.*

for compliance with a legal or regulatory obligation by the controller, the conduct of studies by a research body, for protection of health, life, or physical integrity of the data subject or third parties, among others.

Taking as a parameter the categories of processing based on the type of purpose (EDPS; AEPD, 2024), as described in the section Applications and potential uses of neurotechnologies, some legal scenarios are more appropriate for the uses and applications of neurotechnologies, namely: (i) consent of the data subject, (ii) conducting studies by research bodies, and (iii) health protection. Two methodological observations, however, should be made. First, this brief analysis does not claim to exhaust all the circumstances applicable to the processing of neural data. Second, although it is recognized that in many situations neural data will be classified as sensitive personal data, the possibility of it being classified as non-sensitive data is not excluded in theory, as argued in Section Is neural data personal data?

a) Consent of the data subject (Articles 7, I, and 11, I, of the LGPD)

Consent is defined in the LGPD as the freely, informed, and unambiguous manifestation which the data subject agrees to the processing of their personal data for a given purpose (Article 5, XII, of the LGPD). The adoption of this legal basis "presupposes the possibility of a free, informed, and unambiguous decision-making process by the data subject regarding the use of their personal data for a specific purpose" (ANPD, 2021, p. 21).

The processing of personal data in the field of neurotechnologies raises relevant challenges to the data subject's consent. To a large extent, this stems from the aforementioned complexity not only of the neural data itself (see Section Neural Data) but also of the functioning of these emerging technologies. How can we ensure that the data subject's act will be performed in a freely, informed, specific, and unambiguous manner?

For consent to be a freely manifestation of the data subject's will, the act must be free from defects[23] such as coercion or misrepresentation based on *dark patterns*[24] and misleading patterns (Luguri; Strahilevitz, 2021). Consent may also become invalid due to the absence of free manifes-

23 *Art. 8, § 3, of the LGPD.*

24 *Dark patterns are user interfaces whose designers knowingly confuse users, make it difficult for users to express their actual preferences, or manipulate users into taking certain actions n actions" (Luguri; Strahilevitz, 2021, p. 44).*

tation of will when circumstances indicate that the data subject is at a disadvantage, especially when they may suffer negative consequences if they do not consent to the processing of their data (ANPD, 2021). For that matter, the use of the normative hypothesis of consent is unlikely to be appropriate in applications of neurotechnologies in work and school environments (ICO, 2023), since they are hierarchical or marked by asymmetrical relationships and susceptibility to adverse consequences (e.g., obstacles to career advancement, negative grades or assessments for students) due to disagreement with the processing operation.

Furthermore, the consent required by the Brazilian data protection regime must be informed, which corresponds both to the data subject's right to be informed and to the data processor's duty to inform (Bioni, 2019). One of the greatest challenges in reconciling the normative hypotheses of Articles 7, I, and 11, I, of the LGPD with the processing of data by neurotechnologies is related to the ability of these devices to process neural data without the data subjects being aware of such operations (Ienca *et al.*, 2022; Rainey *et al.*, 2020; UNESCO, 2022), such as the recording and stimulation of signals and brain activity below the threshold of human perception (Bertoni; Ienca, 2024). Given that various cognitive activities occur in the human subconscious, the creation and flow of neural data are elusive to conscious individual control. How, then, can the processing of this data be reconciled with the requirement of prior consent based on adequate information about the content and purpose of the processing operation?

As Ienca *et al.* point out, with regard to neural data, the separation between the data processed and the (nervous) system on the basis of which the data subject makes decisions about its processing is dissolved (Ienca *et al.*, 2022).

Another significant challenge concerns the quality of information that data subjects should receive, as it must be appropriate for their level of understanding. For consent to be effectively informed, it will be necessary to overcome the obstacles inherent in the complexity of neural data and the functioning of neurotechnologies. In other words, processing agents must explain the processing operations, the functioning of the technology, and its objectives in a manner that is understandable to the data subject (EDPS; AEPD, 2024), whether they are adults, children, adolescents, the elderly, or members of other vulnerable groups. Without understanding the processing that will be carried out and for what purpose, there is no possibility of exercising informational self-determination.

Consent must also be specific[25], both in relation to the specific purpose (Article 5, XII, of the LGPD) and in relation to the data being processed (Articles 11, I, and 14, caput, of the LGPD). The considerations on the principle of purpose have already indicated the current difficulty in specifying the exact purposes of processing, given the countless brain signals processed and their nuances (Ienca *et al.*, 2022). These observations extend to the specificity required for consent.

25 *The consent of the data subject must also be provided in in a prominent manner if the neural data is classified as sensitive data.*

In synthesis, although the consent of the data subject is, in theory, an adequate legal basis for the uses and applications of neurotechnologies, there are several obstacles that in practice require a high degree of caution on the part of treatment agents and significant efforts to comply with the legal requirements for valid consent, including for children and adolescents, and other data subjects in vulnerable situations, while observing data protection by design.

b) Other applicable legal scenarios

In the Brazilian legal system, other legal hypotheses may provide normative support for the processing of neural data. Given that the development of neurotechnologies in recent years has been notably driven by academic and interdisciplinary research in the fields of neuroscience, medicine, computer science, among other areas (Vázquez-Guardado, 2020; UNESCO, 2023), the normative provision of Article 7, IV, and Article 11, II, "c" of the LGPD is of crucial importance in the national scenario. These legal hypotheses confer legitimacy on the processing of neural data for academic studies and research (ANPD, 2023), applicable both in situations where neural data consists of non-sensitive data and in those situations where it constitutes, in fact, sensitive personal data.

It is important to note that the special legal regime for the processing of personal data for exclusively academic purposes and for conducting studies (Art. 4, II, "b" and Arts. 7, IV, and 11, II, "c" of the LGPD) does not exempt compliance with other relevant legal parameters (ANPD, 2023b), such as the so-called general principles of data protection and the principles, guidelines, and rules for conducting research with human beings by public or private institutions in Brazil[26]. With regard to conducting neuroscience research involving human subjects and the use of emerging neurotechnologies, Law No. 14874/2024 establishes relevant concepts, such as medical devices and experimental medical devices[27] and legal rules, such as the need to obtain the free and informed consent of research participants[28] (Brazil, 2024a).

Other relevant and appropriate normative hypotheses to ensure the lawfulness of neural data processing can be found in Articles 7, VIII, and 11, II, "f" of the LGPD. In situations where neurotechnologies are authorized for use in a clinical context for the diagnosis and treatment of diseases, health protection will serve as the normative basis for legitimizing the processing of neural data carried out by health professionals.

Although there is no incompatibility, in abstract terms, between LGPD's personal data protection regime and the processing of neural data through neurotechnologies for commercial purposes – that is, beyond medical and scientific research purposes – the possibilities for lawful processing will be more restricted for cases in which neural data qualifies as sensitive data.

‹ neurotechnologies in brazilian context ›

Once we understand what neurotechnologies are, the neural data they process, and the impact of personal data protection regulations, it is essential to map the Brazilian scenario for the development and use of these technologies. This approach will make it possible to gauge the practical repercussions of personal data protection regulations and project future prospects for neurotechnologies and their applications in Brazil.

26 *Resolution No. 466 of the National Health Council (CNS), in force since 2012, establishes standards and guidelines for research involving human subjects, imposing, for example, the requirement of free and informed consent from the participant or their legal representative.*

27 *Art. 2, XVII and XVIII, of Law No. 14784/2024.*

28 *Art. 3, VI, of Law No. 14784/2024.*

This section aims to map the national landscape by identifying medical applications, general commercial uses, and the research and development ecosystem.

Medical applications

In the field of medicine, clinical research[29] in humans[30] helps to prove the efficacy and effectiveness of the use of technologies. Some neurotechnologies (ANVISA), provided they are intended for diagnostic or treatment purposes (ANVISA, 2022). Diagnostic equipment in neurology is essential for assessing and monitoring the health of the nervous system. Among the equipment used for diagnostic purposes, electroencephalograms, magnetic resonance imaging, and computed tomography stand out.

29 *Art. 3, XVII and XXIII, of Law No. 14874/2024.*

30 *Art. 28, of Law No. 14874/2024.*

Newly developed neurotechnologies are incorporated into the National Health System (SUS) after being approved in a technology assessment by the National Committee for Health Technology Incorporation (CONITEC)[31]. CONITEC was created in 2011 by inclusion in the Organic Health Law (Brazil, 1990). These assessments do not directly involve analysis of the risks related to personal data protection and privacy rights, but they are essential to ensure that only neurotechnologies anchored in scientific evidence on its efficacy, accuracy, effectiveness, and safety are adopted in the SUS.

31 *Art. 19-Q, of Law No. 8080/1990.*

The Brazilian Ministry of Health established the SUS Digital Program in 2024. The scope of the program covers technologies, techniques, and approaches that can be integrated with existing neurotechnologies, such as electronic health data recording, data science, artificial intelligence, telehealth, mobile health applications, wearable devices, and the Internet of Things, integrating new technologies into public health policies (Brazil, 2024b).

Another example of the medical application of neurotechnologies in Brazil is in deep brain stimulation implant surgeries, which have been performed in the country for 40 years (Rodrigues, 2024). The implantation of electrodes for brain stimulation, for the treatment of Parkinson's patients and epilepsy, is performed by the SUS. Deep brain stimulator implant surgery is planned for a selected group of patients with Parkinson's disease (Brazil, 2017, p. 8).

Also performed by the SUS, Cochlear Implantation is intended for patients with hearing loss. The procedure "consists of the unilateral surgical implantation of a bundle of electrodes positioned inside the cochlea with the aim of partially replacing the functions of the inner ear (cochlea), transforming sound signals into electrical signals" (Brazil, 2024c). CONITEC found strong evidence of the benefits of treating hearing loss with this neurotechnology (CONITEC, 2014, p. 2).

We can also mention the development of a tool by the company Brain4care, which presents a medical device aimed at clinics and hospitals for non-invasive wireless intracranial pressure monitoring (Brain4Care, 2025). It is a sensor, attached by a band to the patient's head, which captures neurological data. This data is processed by an artificial intelligence system, generating indicators that signal the risk of increased intracranial pressure (Zimmerman, 2024).

Commercial applications for the consumer market

Wearable Electronic Devices that use neurotechnologies are currently available directly to consumers. We highlight two Brazilian neurotechnology companies: Neurobots Pesquisa e Desenvolvimento LTDA and Cycor Cibernética S/A.

Neurobots offers neurofeedback devices for capturing electrical muscle activity with potential use in physical therapy rehabilitation, the development of a hand Exoskeleton Device to aid in the treatment of neurological motor sequelae, team training platforms, and the use of electroencephalographic signals for neurofeedback with potential applications in health treatments (Neurobots, 2025).

Cycor, in turn, presents a more concentrated product exhibition than Neurobots, focusing on Exoskeleton Device for use in multiple scenarios such as medical treatments, increasing the strength of workers in industries, and security and defense forces. It also offers an electronic board for customization, which expands the possibilities for uses and applications for automation by capturing electrical signals from the brain for conversion and operation in machines and systems (Cycor, 2025).

In addition to domestic products, with the advent of globalization and e-commerce, products developed outside the country can be accessed by Brazilian consumers, either through direct purchase from the manufacturer's website, specialized importer websites, or marketplaces. In other words, even if they are not directly produced in the domestic market, it is possible that technological devices, including neurotechnologies, may have as their final recipient a consumer or data subject located in Brazil.

The commercial applications with neurotechnologies currently most present for direct access to the consumer market use neurofeedback equipment that has EEG sensors that send data to mobile devices. This data is used in mobile phone applications for entertainment, to assist health treatments, to assist meditation, or to monitor students' attention levels (Genser; Damianos; Yuste, 2024).

Teaching, research, and development

Educational and research institutions play a fundamental role in generating, disseminating, and strengthening knowledge. In the Brazilian neurotechnology landscape, the Alberto Santos Dumont Institute for Education and Research (ISD), the National Institute of Science and Technology for Responsible Neurotechnology (INCT NeuroTec-R), the Brazilian Institute of Neuroscience and Neurotechnology (BRAINN), and the Renato Archer Information Technology Center (CTI) stand out.

The ISD is a social organization linked to the Ministry of Education (MEC) that operates in the areas of neuroscience and neuroengineering. It comprises the Edmond and Lily Safra International Institute of Neuroscience (IIN-ELS), which conducts research on brain-computer interfaces and neuromodulation. Another branch of IIN-ELS is the Graduate Program in Neuroengineering, which operates as a training center for Brazilian researchers (ISD, 2025).

INCT NeuroTec-R, based at the Federal University of Minas Gerais (UFMG), is responsible for an international research network of public and private institutions. The institute develops neuromodulation projects using non-invasive techniques (Transcranial Focused Ultrasound Stimulation – tFUS, Transcranial Direct Current Stimulation – tDCS) in humans, and invasive techniques (optogenetics, fiber photometry[32]) in animal models and neuroimaging projects using Functional Near-infrared Spectroscopy (fNIRS) to estimate brain activity and Positron Emission Tomography Computed Tomography (PET-CT) to evaluate biomarkers and brain structure (CTMM, 2019).

Linked to the State University of Campinas (UNICAMP), BRAINN developed for the first time in Brazil a small neural probe made of polymers, which allows recording or stimulating brain areas, enabling the realization of research in the country through means of device customization (BRAINN, 2015). There are products being developed and tested in the field of neurotechnology research, but because they are still in the experimental phase, they are not available on the market.

Research and development initiatives are promoted by CTI, a research unit of the Ministry of Science, Technology, and Innovation (Brazil, 2025), which has two national cooperation projects: (i) the project for rehabilitation and assistance devices in neuroscience and neurotechnologies (DReANNs), developed in partnership with UNICAMP; and (ii) the project to form a Cooperation Network in neuroscience and nanotechnology for the development of research on the brain and its mechanisms, together with CEPID/BRAINN, UNICAMP, the Federal University of São Paulo (UNIFESP), and the Federal University of ABC (UFABC)/FAPESP (CTI, 2024, p. 29).

DReANNs aims to "[…] develop assistive and rehabilitation technologies for people with motor and cognitive disabilities […]" (CTI, 2024, p. 29). The lines of development applied to neurotechnologies are: development of prosthetic systems with muscle control by electrical signals; development of rehabilitation protocols involving virtual reality and augmented reality applications coupled with neuromodulation techniques (neurofeedback and transcranial stimulation); development of user-machine interfaces (including brain-computer interfaces) and wearable electronic devices using neurodata processing and machine learning techniques (CTI, 2024, p. 29).

32 *Fiber photometry is a technique that uses a fiber optic cannula to monitor luminescent signals.*

Similarly, the Cooperation Network in neuroscience and nanotechnology for research on the brain and its mechanisms has, among its objectives, the research and production of neural probes and the use of additive manufacturing to develop solutions and devices (CTI, 2024, p. 36).

Initiatives to promote research, development, and innovation have also been gaining market attention, including through the creation of specific funds (Pacete, 2024). One notable example is the case of Neuro Capital (Neuro Capital, 2025), which may provide greater traction to the adoption and implementation of these emerging technologies in the country.

‹ future prospects ›

As noted in previous sections, neurotechnologies have demonstrated potential applicability in a wide range of areas and promise "profound transformations in the way we live, work, and learn" (GPA, 2024, p. 2). Among the most promising applications for the coming decades are: (i) neurodiagnostic tools with artificial intelligence to support medical decision-making; (ii) the development of synthetic memory, digitally reconstructed from personal memory, expanding cognitive capacities; (iii) the use of brain-computer interfaces to restore communication skills in individuals with severe disabilities; (iv) development of neurally controlled prostheses; and (v) cognitive enhancement to improve human performance in higher-order brain functions, such as reasoning and decision-making (Bertoni; Ienca, 2024, p. 4–5).

In the United Kingdom, the ICO (2023, p. 12–16) makes projections for the use of neurotechnology in sectoral markets in the short term (two to three years), medium term (four to five years), and long term (five to seven years). Although this perspective is designed for the British context, the considerations may serve as a guide for the Brazilian scenario.

In the short term, the main sectors involved would be the medical sector, with an increase in the use of invasive neurotechnologies and the development of neuroprostheses; the development of non-medical devices that provide health information, such as non-invasive wearable neural wellness and fitness devices; and the sports sector, to analyze professional athletes' responses to levels of stimulation and concentration. In the medium term, neurotechnologies could be applied in the workplace, in the electronic gaming entertainment industry, and for direct-to-consumer neuromarketing. In the long term, there is potential for application in the education sector and in new forms of assistive communication in the medical field.

In the healthcare sector, even older technologies will continue coexisting with the latest innovations. For example, incremental layers have been added to the recording of electrical brain signals, such as the digitization and remote transmission of data for reporting (which may involve the international transfer of personal data), and may evolve further with increased processing capacity (using data collected to train artificial intelligence algorithms) for the purpose of diagnosing diseases or recognizing patterns applied to non-pathological conditions, such as behaviors associated with mental states of concentration, dispersion, or relaxation.

In order to systematize the trends that may have the greatest impact on the protection of personal data and the protection of data subjects' rights, four trends in the development of neurotechnologies in the coming years are highlighted:

a. The advancement of non-invasive brain-computer interfaces. Although invasive neurotechnologies are more effective to date due to their higher spatial and temporal resolution (Gaudry *et al.*, 2021; Istace; Tracasas, 2024, p. 4), there are limitations related to their adoption. Examples of this are the potential for adverse events (from implantation surgery or resulting from use, such as the possibility of burns), and the reduction in both the quality of neurological signals recorded over time and the impact of stimulation. The development of non-invasive neurotechnologies has progressed rapidly and demonstrated potential beyond the field of scientific research and medical treatments (Gaudry *et al.*, 2021; Istace; Tracasas, 2024, p. 4);

b. The development and commercialization of wearable devices for non-medical purposes. Although most neurotechnologies are still developed for medical purposes, the notable market interest already drives the production of these emerging technologies and their commercialization in sectors that are little or not regulated (Istace; Tracasas, 2024, p. 7; Navarro *et al.*, 2023, p. 28). This, incidentally, has been considered an incentive factor incentive for research and innovation in applications of non-invasive and wearable neurotechnologies (Istace; Tracasas, 2024, p. 7). With commercialization in the consumer market, in addition to more immediate safety risks, the long-term implications for mental health of the use of non-invasive brain monitors and neuromodulators, for example, lack scientific evidence (Wexler; Reiner, 2019). Due to the processing activity and the characteristics of the neural data involved, the wider dissemination of neurotechnologies will most likely create situations of vulnerability or aggravate existing situations, implying risks to privacy rights and personal data protection.

c. Interweaving neurotechnologies with artificial intelligence. The integration between artificial intelligence systems and machine learning-based approaches in the development of neurotechnologies and their application is a reality that will endure (UNESCO, 2023; Yuste, 2023; UN, 2024; Istace; Tracasas, 2024). In relation to brain-computer interfaces, it is stated, for example, that one of the greatest advantages that machine learning approaches have in the field of these technologies is the ability to obtain real-time or near real-time modulation of training parameters and subsequent adjustments in response to active real-time feedback (Zhang *et al.*, 2020). An important consequence of this intertwining of technologies and areas is the sharing of ethical and legal challenges raised by the development and use of artificial intelligence systems, such as algorithmic biases and unlawful discrimination, inference of emotional states in hierarchical institutional environments, as well as the adoption of these systems for manipulative practices.

d. Intensification of the volume of data generated and shared for research purposes. In recent decades, neurotechnologies have enabled major advances in neuroscience and have in fact transformed the way research is conducted in this field of knowledge, moving from the traditional model of projects led by a single researcher to a model based on joint efforts involving teams, consortia and data observatories (Kim *et al.*, 2025, p. 814). Sharing data is therefore crucial. In addition, there has been exponential progress in the volume and scale of data generated from these technologies, which has enabled the formation of immense databases. However, experts say that "While this rapid progress threatens to leave us drowning in data and complexity, it also holds the promise of novel insights that can push the field forward" (Kim *et al.*, 2025, p. 814). Thus, the generation of large volumes of neural *data – big* (neural) data – and the requirement for data sharing in neuroscience research raise non-trivial questions about compatibility with the principles of purpose, adequacy, and necessity, as well as about the normative bases that legitimize the sharing of neural data.

‹ final considerations ›

The study aimed to understand the landscape of neurotechnologies and their implications for personal data protection in the Brazilian context. For this purpose, based on a review of the literature and documentation, the concepts of neurotechnologies and neural data were explored, the potential uses of these technologies were presented, legal issues relevant to personal data protection were discussed, and the current applications and future prospects of neurotechnologies were mapped out.

The direct interaction of neurotechnologies with the brain and nervous system, and the data that are processed in this process, raise questions about the personal nature of neural data. Although the LGPD does not expressly address neural data and its definition, the broad concept of personal data adopted in Brazilian law is capable of encompassing neural data relating to an identified or identifiable natural person. It is worth noting that such data, whether provided, observed, or inferred, may constitute sensitive personal data if it reveals aspects of personality referred to in Article 5, II, of the LGPD, such as health-related data. As a result of the classification of neural data as personal data, the personal data protection regime established by the LGPD applies to the processing of neural data, including the principles of data protection and the need for a legal basis to ensure the lawfulness of the processing of such data.

When observing neurotechnologies in the Brazilian context, it was possible to see direct applications in the field of health and, on a smaller scale but with a growing trend, in commercial applications for direct consumption by consumers or data subjects. In research and development activities, initiatives focused on innovation were identified, formed by research and teaching institutes and the development of investment funds dealing with neuromodulation, neurostimulation, neuroimaging, neuroprostheses, and brain-computer interfaces.

Interest in neurotechnologies has grown, driven by integration with artificial intelligence and machine learning. In addition to scientific progress, the development of neurotechnologies is also influenced by economic interests with a market projected to grow signficantly.

Although neurotechnologies were previously restricted to the field of health, today they have diverse applications for direct consumption by the population, in activities ranging from leisure to education, as well as being used by the market in activities from marketing to employee recruitment.

With such a wide range of applications and prospects for future expansion, it is essential not only to constantly monitor technological advances in order to understand their impact on data subjects' rights to privacy and personal data protection. It is also necessary to ensure that personal data protection standards and principles are observed in the development and application of neurotechnologies, especially data protection *by design* approach.

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