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Neuralink's brain-computer interfaces: medical innovations and ethical challenges

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Neuralink's advancements in brain-computer interface (BCI) technology have positioned the company as a leader in this emerging field. The first human implant in 2024, followed by subsequent developments such as the Blindsight implant for vision restoration, marks a significant milestone in neurotechnology. Neuralink's innovations, including miniaturized devices and robotic implantation techniques, promise transformative applications for individuals with neurological conditions. However, these advancements raise critical clinical, ethical, and regulatory questions. From a clinical perspective, BCIs show potential in addressing severe disabilities, but the long-term effects, safety, and usability of these devices remain uncertain. Ethical concerns focus on informed consent, patient autonomy, and the implications of integrating BCIs into human identity. The bidirectional nature of Neuralink's devices introduces privacy risks, highlighting the need for stringent oversight to safeguard sensitive neural data. Furthermore, the company's initial lack of transparency, such as delayed trial registration, has drawn criticism from the scientific community for deviating from established norms of research ethics. Regulatory challenges also emerge as BCIs intersect with frameworks governing data privacy, medical devices, and artificial intelligence. The lack of a cohesive legal framework for neurotechnology underscores the importance of developing comprehensive standards to balance innovation with the protection of fundamental rights. Finally, philosophical questions about human identity and agency arise as BCIs blur the boundaries between mind, body, and technology. As BCI technology advances, it is imperative for the scientific community, policymakers, and society to collaborate in addressing the opportunities and risks posed by this transformative innovation.

KEYWORDS

privacy risks, human enhancement, neuroethics, Neuralink, brain computer interface

1 Introduction: Neuralink's BCIs

Although neurotechnologies were initially developed in research and clinical settings to treat patients with motor or neuropsychiatric impairments, the growing expansion of their non-medical applications has increasingly attracted private companies eager to advance and commercialize these technologies. This growing trend raises significant concerns, as it is one

of the areas where the rapid and often unchecked pace of technological innovation urgently demands critical theoretical scrutiny and the development of a sound ethical framework. On January 29, 2024, a post on X by Elon Musk attracted global media attention due to Neuralink's implantation of an electronic device, called Telepathy N1, into the brain of a disabled individual.[1] The device promises to enable direct communication between the patient and a computer, allowing the patient to move and operate in their environment, overcoming the limitations imposed by their condition (a quadriplegia that blocks all limbs). The scientific rationale, in brief, is that the electrodes inserted into the cortex record neuronal activity corresponding to the intention to move, translate it, and transmit it wirelessly via the chip placed in the skull (Drew, 2024).

This led to the evocative yet imprecise summary of "mind-controlled devices." The announcement provoked both "technological enthusiasm" ("Has the perfect union between humanity and technology been achieved?") and "neuroskeptical alarm" ("All the shadows of an enhancement without ethics," just to summarise some media headlines). However, the information provided about the procedure has initially been quite limited, and much of what can be reconstructed comes from communications by the company and Musk himself.

Later, on March 20, the same entrepreneur released a video of the patient, 29 years old, paralysed for 8 years after a diving accident, describing how he can move the computer cursor and therefore play chess, videogames, and post messages on X.[2] The young man describes himself as in excellent condition, and talks about the device as easy to use, although "not everything is perfect." In a subsequent presentation, with the patient present, some data on the device's usage times were provided. Musk also mentioned that the next step will be an attempt to restore sight in blind individuals through direct cortical stimulation.

In August 2024, Neuralink implanted its N1 device in a second human participant, referred to as "Alex." Alex, who suffered a spinal cord injury, demonstrated the ability to control digital devices using only "his thoughts," as it has commonly (and misleadingly) been described the technical process involved.

In September 2024, Neuralink's experimental Blindsight implant received "breakthrough device" status from the U.S. Food and Drug Administration (FDA). The Blindsight implant aims to restore vision in blind individuals by directly stimulating the visual cortex, offering hope to those who have lost their sight, provided their visual cortex remains intact.

In November 2024, Neuralink announced the initiation of the CONVOY Study, a feasibility trial aimed at extending the capabilities of the N1 implant to control assistive robotic arms. This study represents a step toward restoring digital and physical capabilities for individuals with mobility challenges.

In light of this undeniable technical advancement (other similar implants have already been made, and Neuralink's is expected to be more efficient—completely wireless, including charging—and less invasive), it is important to clarify and explore the various clinical, ethical, regulatory, social, and philosophical aspects raised by progress in neurotechnology research (cf. Waisberg et al., 2024; Armocida et al., 2024; Ienca et al., 2025).

This article was conceived in a *Delphi-like spirit* through an instant workshop that brought together the authors at the University of Milan in February 2024. The initial multidisciplinary discussion held on that occasion subsequently evolved into the present article. This work adopts an analytical and critical approach, drawing on published information and other reliable sources concerning the Neuralink BCI experiment. The methodology is based on each author's expertise in their respective field, as reflected in the article's division into sections, as well as on the collective discussion among all 10 workshop participants, both during the event and in the subsequent drafting of the text.

2 Clinical aspects

From a neurosurgical perspective, invasive techniques (Cortical Brain Stimulation or CBS) and minimally invasive techniques (Deep Brain Stimulation or DBS) for brain neuromodulation have been in clinical use for several decades, with promising results for treating neurological disorders (Sironi, 2011). DBS for certain diseases (Parkinson's disease, some psychiatric disorders, Tourette syndrome) in cases of inadequate pharmacological response provides positive therapeutic responses in a high percentage of cases. An external stimulator (a pacemaker implanted under the skin and adjustable based on the type of stimulation to be sent to the brain targets) sends electrical impulses capable of "activating" the neuronal nuclei identified for neuromodulation. From a neuroethical perspective, in these situations, once the patient's informed consent is obtained, the intervention is legitimized as it is a therapeutic procedure for sick individuals (Smith et al., 2023).

Concerning brain-computer interface (BCI), the first intervention on a human patient dates back to 1998. In this case, brain stimuli, captured through microelectrodes placed on certain brain areas (motor parietal cortex, temporal cortex), send their signals to a computer that decodes them in such a way that they can be used to perform actions otherwise impossible due to brain injuries (e.g., language disorders) or spinal cord damages (e.g., tetraplegia or paraplegia; Lebedev et al., 2011).

The probably most successful case so far is the "digital bridge," developed at the University of Lausanne, where researchers and clinicians created a connection between the brain of a man paralyzed due to an accident and the portion of his spinal cord below the lesion, allowing him to walk again. When the man "thought" about walking, the brain electrodes detected the electrical signals from the cortex, which were decoded through a wearable wireless control system in a backpack and transmitted in real-time to the spinal cord, where other electrodes applied there performed the function of the active interface (Lorach et al., 2023).

Several companies (Precision Neuroscience, Synchron Medical, Paradromics, Blackrock Neurotech, BrainGate, and Corticale, to name just a few), have been working on developing more advanced systems of this kind. In particular, reference can be made to several recent studies. A minimally invasive BCI has been developed to be implanted via blood vessels rather than open-brain surgery demonstrating an alternative, less invasive approach to BCI implantation (Mitchell et al.,

1 Elon Musk: Neuralink and the Future of Humanity | Lex Fridman Podcast #438 [Internet]. 2 August 2024. https://www.youtube.com/watch?v=Kbk9BiPhm7o.

2 Neuralink livestream shows paralyzed person playing chess on laptop. NBC News, March 20, 2024. https://www.nbcnews.com/tech/tech-news/neuralink-livestream-shows-paralyzed-person-playing-chess-laptop-rcna144374.

2023), while Oxley et al. (2021) described "the first-in-human experience of a minimally invasive, fully implanted, wireless, ambulatory motor neuroprosthesis using an endovascular stent-electrode array." Some researchers have been focusing on adaptive BCI systems that use machine learning to improve neural signal decoding over time, so enhancing long-term usability by allowing the BCI to adjust dynamically to individual users (Jin et al., 2024). Concerning another feature, studies have been conducted using intracortical electrodes to decode speech from neural signals, enabling silent communication for patients with severe paralysis (Moses et al., 2021).

Neuralink, therefore, is not an absolute pioneer in this field, although the technological innovations of their first human implant relate to the miniaturisation of the intracranial device and the large number (over a thousand compared to the usual hundreds) of very fine microelectrodes placed in the cerebral cortex. The robotic procedure for implanting the device is also noteworthy. These technical innovations, combined with the substantial availability of funding, place Neuralink at the forefront of this type of research. At the same time, they demand a profound sense of responsibility toward patients, the scientific community, and society as a whole.

3 Bioethical and neuroethical aspects

Neuralink's experimentation promises to offer significant benefits for various types of patients with neurological conditions. The primary concerns are the safety of the implant and the device (Folgieri, 2017). It is important to obtain reliable data on the device's proper functioning, and potential medium-and long-term side effects, including signal quality, device longevity, and user experience. The probability that removal or replacement of the device may be required and the risks associated with such interventions should also be estimated. There is also the potential danger of sudden malfunction, as we are talking about a system that controls external effectors, which could cause harm to third parties. Neuralink should provide more information on these aspects and make the protocol publicly available.

Furthermore, one may question whether the brain could be overloaded through interaction with external devices. The mechanism of brain action through BCI is still to be tested over the long term. It is possible that the brain's plasticity compensates for the new modes of interaction with the external environment mediated by the digital interface. However, phenomena of subjective disorientation or strictly neurological disorders cannot be ruled out. Only prolonged use across a large number of patients will provide definitive answers. This, however, should make us cautious in experimentation, raising challenging questions about what constitutes an acceptable level of risk. Initially, decisions will need to rely on an estimated cost–benefit analysis relative to the patient's condition and the improvements BCI can deliver in the short term.

Among the ethical aspects and risk communication, it must be considered that patients with severe disabilities, such as those with locked-in syndrome or tetraplegia, might be so eager to improve their condition that they accept high risks without fully understanding the implications (Klein and Ojemann, 2016). However, it is crucial to ensure that these patients maintain full decision-making autonomy, even when agreeing to undergo experimental or insufficiently tested treatments, provided they are adequately informed of the potential risks and benefits.

Another delicate issue is the guarantee of continuous care by private companies. The integration of a BCI, like the one implanted by Neuralink, makes it an essential part of the individual, and its maintenance becomes critical for the patient's well-being. What will happen if the company ceases operations, or the costs become prohibitive for the patient? It seems reasonable to regulate the sector to account for these not-so-remote eventualities (Cassinadri and Ienca, 2024).

Furthermore, the system developed by Neuralink (as well as those from other companies working in this field) is bidirectional, raising uncertainties both regarding the potential use of the device as a means of enhancing the physical and mental abilities of healthy individuals (and not only for the sick) and the possibility of extracting information that invades the individual's privacy. These new brain-machine interface capabilities open fascinating prospects in neuroscience (the dream of creating "cyborgs" and dynamically interacting with Artificial Intelligence becomes reality), but all of this requires careful critical reflection on the use of this neurotechnology.

Privacy concerns related to BCI in clinical settings are particularly complex. At first glance, they might appear secondary to the patient's well-being, as BCIs can greatly enhance both physical and mental conditions (consider, for instance, a tetraplegic individual who can independently use a computer). However, once significant abilities are regained, individuals may find their privacy threatened precisely because of the interface that has substantially improved their well-being. Therefore, it is crucial to once again assess the costs and benefits in advance, considering the patient's condition and preferences, while fully disclosing all the implications of using BCIs (Andorno and Lavazza, 2023).

4 Research ethics aspects

In May 2023, Neuralink received FDA approval (after a rejection in 2022) for human clinical trials but the traditional process of scientific dissemination, which involves publishing results in peer-reviewed journals, specialized conferences, and public databases, is crucial for ensuring transparency, verifiability, and integrity in scientific research (Brownson et al., 2018). This approach allows the scientific community and the public to critically assess the methods, results, and ethical implications of studies. However, Neuralink's practice of communicating significant updates via social media platforms signals a deviation from these established standards, raising concerns about transparency and ethical accountability.

From the perspective of research ethics, the failure to register Neuralink's first clinical trial in the ClinicalTrials.gov database seemed to violate the fundamental ethical guidelines for biomedical research, such as the Declaration of Helsinki (De Angelis et al., 2004). The study record was then submitted to ClinicalTrials.gov on May 21, 2024, before the implantation of a second patient.

The initial omission made it difficult for the scientific community and the public to evaluate the safety, efficacy, and ethics of the conducted research. Indeed, preregistration of clinical trials is a key practice in biomedical research for several ethical reasons, ranging from transparency and accountability to the protection of participants (DeVito et al., 2020). This procedure involves registering the study in a public database before data collection begins, detailing the study's design, objectives, hypotheses, measurements, and planned analyses.

This practice supports the integrity of research and strengthens public trust in scientific results for four main reasons. First, preregistering a clinical trial means making the study's objectives and methodologies public before it begins (Nosek et al., 2018). This increases transparency, allowing the scientific community and the public to access clear and detailed information about ongoing studies. Transparency is crucial for building and maintaining trust in the research process, highlighting the commitment of scientists to honesty and integrity.

Second, preregistration helps prevent outcome switching, a practice that involves modifying the objectives or primary outcomes of a study after the data have been observed. Such practices can lead to distortions in research results and potentially misleading conclusions. Preregistration sets the study's goals before data collection begins, reducing the risk of selective reporting and increasing the validity and credibility of the scientific results.

Third, preregistration highlights the responsibility of scientists to the scientific community and study participants. By clearly indicating the study's design and objectives before data collection starts, researchers commit to following a predetermined course, increasing accountability for their actions and decisions. This is particularly important in studies involving delicate ethical issues or the well-being of participants.

Finally, preregistration contributes to science by providing a comprehensive view of all conducted studies, including those that may not lead to significant or publishable results. This helps combat the file drawer problem, the tendency to not publish studies with negative or insignificant results. By making all preregistered studies public, the scientific community can have a completer and more accurate picture of the research landscape, promoting a more holistic and informed advancement of science.

5 Legal aspects

Brain-computer interfaces (BCIs) like those from Neuralink significantly raise significant concerns regarding the protection of human rights both in the context of scientific and technological research and in the deployment of such devices within the consumer market. The sphere of freedom must be protected from both public (especially in non-democratic regimes) and private powers (for major tech players), as well as from third parties (malicious actors). From this perspective, the notion of freedom encompasses both the bodily dimension (if the device requires surgical procedures) and the "mental" dimension (cognition, memory, sensory processing, etc.), which may be disturbed or violated by the manipulation of brain signals through BCIs.

It is also essential to ensure the protection of the physical and mental integrity of the BCI user in terms of device safety. Additionally, the widespread development of BCIs also contributes to the advancement of certain rights, such as the right to autonomy and social inclusion for individuals with disabilities (e.g., through communication tools and assistive technologies) and the right to health (e.g., by enabling recovery from psychiatric or motor disorders).

Medical and non-medical uses of the BCIs may have an impact on the exercise of rights with both economic (e.g., purchasing goods and services) and personal implications (e.g., providing informed consent or refusing data processing and medical interventions, especially when the person is vulnerable: Pizzetti, 2020). In these contexts, it is essential to guarantee that the user's intentions are accurately represented and that the possibility of disconnecting from the interface remains available at all times.

Examining the legal aspects may necessitate, from a methodological perspective, consideration of various factors. These include legal doctrine—given that neurorights have predominantly been shaped by legal scholars to date—as well as legislative provisions within a multilevel legal framework. This is particularly relevant because neurotechnologies affect fundamental rights that are recognized and protected at both supranational and national levels. Furthermore, the tools of legal interpretation and analogy must be employed, as in some jurisdictions, neurotechnologies continue to be governed by statutory provisions pertaining to medical devices, electronic products that could be — but not necessarily are — neurological (which may include AI software or hardware), and related rights — which are contiguous but not exactly tailored on neurorights — such as personal psycho-physiological integrity and privacy.

While some authors advocate for the adoption of new rights, i.e., neuro-rights to respond to the challenges resulting from the potential of this technology (Ienca and Andorno, 2017; Yuste et al., 2021), other authors claim that rights recognized in national constitutions and international instruments can be updated to provide appropriate protection in this context (Bublitz, 2024; Ligthart, 2020). In any case, when establishing the framework for fundamental neuro-rights, it is essential to consider the necessary balance between competing interests, as well as the importance of the purpose for which the device is employed.

The development of neurotechnology in medicine has brought great hopes to patients with neurological disorders or mental illnesses. But what happens when these methods for recording, interpreting, or altering brain activity leave the clinical arena, governed by strict standards and bioethical norms, and become a product available for consumers?

On one hand, the aggregation and analysis of brain data obtained through these technologies can be framed within the debates on privacy protection (Field, 2024). However, when neurotechnologies available on the market do not only collect data but alter brain activity different risks arise (Sosa Navarro and Dura-Bernal, 2023).

Normative responses to these risks in the European Union and the United States differ: while in the EU, the rule is the medicalization of many neurotechnological devices (considered Class III, high risk), to which the EU Regulation 2017/745 on medical devices applies (Gulotta, 2024), in the United States, consumer-directed neurotechnologies may avoid being classified as medical devices by claiming a wellness purpose. Therefore, if the risk associated with its use is low, the device will be considered a consumer product, subject to consumer product safety and advertising regulations (Wexler and Reiner, 2019).

However, this trend has partially been reversed recently. Both Colorado and California have enacted state laws to classify "neural data" — information generated by measuring the activity of an individual's central or peripheral nervous system (including the spinal cord), either by or with the assistance of a "device" — as "sensitive personal information" under their respective Data Privacy Laws (section 1798.140 of the California Civil Code and section 6-1-1303 of the Colorado Revised Statutes). As a result, in these two American

states, neural data is now subject to the (highest) standards required for sensitive personal data, including strict guidelines on consumer consent, limitations on data collection and retention, security measures, and individuals' rights to access, delete, and restrict data processing. In Spain, the national government has introduced a non-statutory instrument of "soft law," known as the Charter of Digital Rights ("*Carta de Derechos Digitales*").

This Charter aims to adapt citizens' rights to the digital environment and serves as a guide for shaping public policies in this area. It also specifically recognises the "neuro-rights," which encompass individual self-control over personal identity and autonomy in decision-making, as well as the security and privacy of data related to or acquired through neural processes. It also includes regulations regarding devices that could influence bodily and psychological integrity and instruments that may realize cognitive enhancement (Article XXVI). In Chile, constitutional reform has amended the Constitution of 1980 to include a provision that mandates the protection of individual brain signals ("*actividad cerebral*") and the data derived from those signals under the right to physical and psychological liberty (article 19, 1st sect.). This aims to safeguard the physical and psychological integrity of individuals, as well as to promote the wellness of the person.

This being said legislators on both sides of the Atlantic appear to be primarily concerned with the safety and health risks associated with their use, overlooking the impact on mental integrity, autonomy, freedom of thought, and the values related to them. In light of the above, since 2019, international organizations such as the Council of Europe (Report, COE, 2021), the OECD (9 principles, OECD, 2019) and UNESCO (report 2021 and upcoming recommendation; UNESCO, 2021) have responded to this governance gap by adopting statements addressing the ethical and human rights aspects of neurotechnologies. In the same line, the UN Human Rights Council has recently adopted a report drafted by the Human Rights Advisory Committee on the impact, opportunities and challenges of neurotechnology about promoting and protecting all human rights (UN Human Rights Council, 2024).

Although neuro-devices and artificial intelligence (AI) may not be directly related technologies, they could increasingly be combined today and even more in the future. For instance, brain-computer interfaces (BCI) might leverage AI software to better analyze and interpret the neuro-patterns generated by individuals using these devices for various purposes, both medical and non-medical, including critical situations like labour and educational environments. From this perspective, neurotechnology could be subject to regulations set forth by the European Union (EU) for AI (EU regulation No. 2024/1689, known as the "AI Act.").

The new rules identify, on a risks-basis, the AI practices deemed unacceptable in the EU due to their potential to violate human rights and fundamental European principles. Examples of prohibited practices include those that could distort behaviour subliminally, predict personality traits for social scoring, profile individuals for potential criminal behaviour, infer emotions on the workplace or educational settings (except for medical or safety purposes), or deduce political opinions, religious beliefs, or sexual orientations (as outlined in Article 5). The regulation also specifies the AI systems that are permitted within EU territory, but only under stringent conditions for producers, importers, and deployers, which include conducting a human rights impact assessment, particularly for systems categorized as high-risk (as detailed in Article 6 and subsequent articles, along with Annex III).

The fact that neurodevices, such as BCIs, can now adhere to the rules established for AI systems in Europe — if they utilize AI — represents significant progress in protecting individual rights concerning these neurotechnologies on European soil.

Furthermore, brain data should be understood as "data relating to the functioning or structure of the human brain of an identified or identifiable individual, including unique information about their physiology, health, or mental states" (OECD). As a consequence, if the brain data are processed by a neuro-device capable of revealing sensitive personal information, this brain data must also comply with the general European data privacy law (EU regulation No. 2016/679, also known as the "GDPR"), particularly concerning regulations applied to "sensitive data" (Rainey et al., 2020).

So, we have some sector-specific rules (such as those governing privacy, AI, medical devices, and products), that also apply to neuro-devices, aiming to protect human dignity and personal rights. However, we still lack a comprehensive legal framework specifically addressing neurotechnologies "*per se*." In the EU, the multiplicity of different legal sources — such as GDPR, AI Act, MD Regulation — that apply to the BCI might also create conflicts of laws, difficulty in interpretation, and uncertainty for citizens and entrepreneurs.

Therefore, it is crucial to develop legal principles and regulations at both the international level and beyond that safeguard and promote individual liberty rights (Farahany, 2023) and rights related to social inclusion (Fins, 2022) in the context of neurotechnologies.

6 Psychological-philosophical aspects

Whether it is a new direction or a simple evolution of techniques already well known in the world of rehabilitative medicine or applied neuroscience research (such as brain-computer interfaces), the suggestion of overcoming the thought-action boundaries raises questions for research and society at large. Wanting to limit our present considerations only to the motor field as it currently exists, and not opening further scenarios for the extension of the device to higher-order functions, there are three critical issues that come to our attention, questions that require careful examination, although they may not provide immediate answers:

How does our sense of agency change?

What to do with "embodied" knowledge?

What role does action mirroring play in developing a sense of social co-participation?

First, the sense of agency (meaning being agents in the world through our actions) (Balconi, 2012) that originates from performing actions, from sensory and proprioceptive feedback, which enables the development of body ownership, is at the core of the sense of being the author of the action (authorship) and more broadly of personal identity as an agent in the world, with full responsibility for wanting, thinking, and acting. Another distinction is between *physical actions* and *mental actions*. In general physical actions involve the production of causal effects in the external world through movements of the body of the agent, while mental actions, such as pretending or remembering a name, do not. Here we consider the phenomenology of physical actions, in terms of a sense of oneself as a physical agent producing physical effects in the world via its bodily interactions with it

(Jeannerod, 2006) What scenarios can open if the mediation of action to act in the world, modifying it, is removed?

Second, as cognitive neuroscience has shown us, the brain (from childhood onward) builds abstract, high-level knowledge based on sensory experience (Varela et al., 1991), mediated by seeing, touching, and manipulating the things in the world, which then become thoughts, but always anchored to that specific "embodied" sensory experience, as language suggests, preserving this embodied nature of knowing: what nature would a new "disembodied thought" have?

Finally, mirroring mechanisms (from mirror neurons onward) which see the observation of the other agent as an opportunity for reflection, fundamental to recognizing "the self in the other" (Balconi and Vanutelli, 2017), developing a sense of empathy, and ultimately socialization built on interaction. Will a person with a soft, disembodied agency be more solipsistic? It's possible, but we can certainly say that applications like those of Neuralink promote the primacy of thought over action, eliminating its demarcation line.

Another potentially critical aspect that deserves mention is that the entirely "mental" nature of the relationship with the computer, without the mediation of artificial limbs, deepens the phenomenon of self-disembodiment: the individual can conceive themselves as "extended" beyond their body into a complex entity that integrates the computer within itself. This can change the experience of the self and may potentially test the authenticity of the subject's conscious experience (Steinberg and Steinberg, 2007). If we adopt a minimal definition of the posthuman, as an individual who possesses at least one posthuman capability (Bostrom, 2008), one could even say that the individual with this implanted device is posthuman.

Indeed, Neuralink and similar new technologies raise deep philosophical questions concerning our very human nature. We must ask ourselves whether these interventions could lead to a fundamental change in our identity, transforming humans into cyborgs, i.e., humansa hybrid creatures between human and machine. Would changing such aspects of our nature be inherently negative, or would it present some benefits. In the end, we would need to figure out whether merging with machines would be overall advantageous or disadvantageous, trying not to base our evaluations only on a "human prejudice" we might have towards keeping our species fully carbon-based as it has been so far.

It can be speculated that the challenges of integrating something external and non-biological into one's identity is a price worth paying, in exchange for improving the quality of life and communication with the environment achievable for patients eligible for this treatment. Considering such benefits does not necessarily entail that Neuralink and future similar technologies will overall have a positive impact on our lives and on the lives of future people. However, we need to make sure that these potential benefits do not overshadow the possible downsides So, this kind of research must be followed with care, as there is a risk that, by further proceeding along the path of hybridizing the body with non-biological parts, we may end up compromising in patients authentically human life experience (Reichlin, 2025).

Moreover, we need to understand whether the introduction of BCIs could interfere with our autonomy. It is possible that the acceleration of the connection between thought and action, or the limitation of inhibitory brakes, could weaken our decision-making freedom, or conversely, increase it, especially for those who are physically limited and unable to perform actions that a person would normally do independently (Friedrich et al., 2018).

A related issue is that of responsibility. How can we determine moral and legal responsibility for actions performed through a BCI? It is difficult to establish whether an individual genuinely intended to act or was crucially influenced by a malfunctioning device or external manipulation, such as hacking the system.

Finally, the introduction of BCIs raises the future possibility of brain uploading, or creating a copy of the human brain. This represents a significant shift in our understanding of the mind and opens new possibilities for the indefinite extension of human life, but it also raises deep ethical and philosophical questions concerning what kind of experience of "oneself" can be had by someone whose brain content was uploaded or copied, and whether there can be any link with the individual's previous mental life (Cappuccio, 2017). These issues also require careful reflection and extensive discussion (Minerva, 2023).

7 Enhancement aspects

What is peculiar about Neuralink's project, and what—beyond Musk's popularity—can help explain the interest (and sometimes concern) that this BCI has generated—interest not seen with other devices—is the explicit reference to its potential non-therapeutic applications. Most devices in use or under experimentation are designed solely, or primarily, to help those suffering from a condition that makes it difficult or impossible to perform certain ordinary life functions, with enhancing purposes being mostly an academic concern (e.g., Kaimara et al., 2020). Neuralink's official website, however, is very clear in stating that its goal is twofold: "To create a generalized brain interface to restore autonomy to people with unmet medical needs today and unlock human potential tomorrow."

It is this second goal that justifies the particular attention given to the application of the device not in individuals with some disabling condition, but in healthy individuals, "to unlock their human potential." Such interventions have been widely discussed in the neuroethical debate for decades under the label of human enhancement (Lavazza and Colzato, 2018; Vilaça and Lavazza, 2022). Without taking excessively optimistic or pessimistic positions regarding the potential and risks of this use, it is important to consider the objections and issues raised in that debate to understand whether, and to what extent, we deem the enhancement use of BCIs desirable.

One might indeed ask what it means to "unlock human potential," what this potential is, and how we can be sure that factors such as commercial interests are not the ones determining the desired functions or potentials. What do we consider essential to preserve in human beings as we know them today, and what should be improved? Who can decide on such matters? If Neuralink's device becomes available on the open market and has significant effects on crucial aspects of our person—unlocking the potential mentioned on the website—will it make labor competition less equitable? Will its cost allow everyone who wants to use it to do so, or will it be prohibitively expensive for some, increasing the already significant positional advantage of certain groups? These are questions that also involve legal aspects, both from the perspective of the social responsibility of individual choices and, conversely, in relation to the protection of fundamental rights from enhancement requirements imposed for public interest reasons in specific contexts (e.g., military).

It is too early for some of these questions, as Neuralink is still in the experimental phase on a single patient, but it is important that

cases like this provoke broader reflection. While the path is long, Neuralink is moving quickly, and considering the potential enhancement use of this technology is useful for evaluating possible regulations, as well as for future, even more advanced devices. Thinking ahead about desirability is essential to avoid being swayed by unfounded enthusiasm or fears and to better understand and decide more consciously what we consider socially useful or permissible—not just for the therapeutic use of BCIs but also for their possible enhancement use (Gordon and Seth, 2024).

8 Discussion: responsibility in innovation towards what ends?

The Neuralink case (and similar experiments already attempted, as previously noted) leads us to observe both the finger and the moon; an operation that common sense would deem inadvisable but one that we cannot avoid, because the big players in technoscience—whether in the digital sector or Musk's many ventures—raise the question: to what knowledge will power go?

Whether it involves understanding whether the data extracted from experiments is regulated by existing norms (innovation, as we know, is not "normal," hard to regulate), or considering the impact on the public sphere of a "scientific" announcement made via social networks owned by the entrepreneur-scientist, we collectively face the issue of public scrutiny over innovation processes.

In fact, when it comes to designing not only updated research policies but also new neurorights (*habeas corpus, habeas mentem*), it is inevitable to observe that neuroscience, like life sciences or artificial intelligence, has taken the debate on the "crisis of expert knowledge" outside academia, transferring the trust issue (whom do I trust?) directly to the public sphere (Farina et al., 2024). As soon as humans know and can do more, the fight immediately begins to define toward which ends this added power—innovation—should be directed.

This is the theme evoked by responsibility in innovation, whose practices have been institutionalized since the 2000s under the concept of Responsible Research and Innovation (RRI; Burget et al., 2017). Tools such as consensus conferences, citizen juries, and moments of public deliberation have spread, involving citizens, stakeholders, and institutions when dealing with public investments—or regulating—controversial technologies. On its own, RRI will not resolve the increasingly open issue of the relationship between technoscience and society; but it is necessary to place it in the broader context of science diplomacy.

If the Chinese Ministry of Science and Technology has included brain-computer interfaces among the seven strategic innovation areas for the Party,[3] and if 8 h after Neuralink's announcement Chinese social media channels claimed similar experiments, we have enough data to remind ourselves, as a community, that on the neuroethics front, it's not just about advancements in research or the market, but defining a significant part of our social framework in this century. Therefore, it is important not to underestimate the implications of responsibility and the tools we adopt to implement them in practice.

3 http://www.china.org.cn/china/Off_the_Wire/2024-03/31/content_117097005.htm?utm_source=chatgpt.com.

9 Conclusion

It is ultimately difficult to underestimate the impact and significance of the BCI project undertaken by Neuralink, particularly with its initial applications in clinical contexts. If these efforts prove successful, the potential for using BCIs in enhancing healthy individuals, as stated by the company itself (Farina and Lavazza, 2024), will emerge. In such a case, ethical and social oversight will need to be even more rigorous and meticulous than it has been for medical applications.

For instance, it has been noted that "Neuralink asks humanity to imagine a world where significant aspects of health care are delivered via *technological systems* rather than *health care*. It further compels humanity to conclude that this shifts away from care and towards function is crucial due to humanity's expanding and ageing population, for which there are not enough healthcare professionals to service" (Miah, 2025).

As highlighted in the analysis conducted thus far, intervening in the brain—and therefore the mind—entails a range of sensitive issues that must all be addressed with the utmost care. The fact that this endeavour is being led by a company owned by the world's wealthiest individual in 2024 adds further complexity from political and social perspectives.

For all these reasons, it is crucial that the scientific community remains vigilant in guiding a process that is extraordinarily promising but also carries potential risks requiring careful ethical oversight.

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