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An overview of Artificial Intelligence, Ethic and Neuromodulation

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Abstract. Based on advances in computing and devices as an extension of the human body, new technologies focused on neuromodulation and with the help of artificial intelligence, can generate lucid dreams and even improve concentration. With noise cancellation through devices such as smart hearing aids or with the generation of devices that detect and modify brain waves, the human body has been empowered towards mental conditions and, in a sense, towards improving the quality of life through sleep. of life through sleep. However, we would be at a point where the ethics and philosophy of technology ethics and the philosophy of technology converge to identify the use of such devices to improve human devices to improve human conditions without overstepping the legal and ethical realm in their use.

Keywords: Neuromodulation, Artificial Intelligence, Technology Ethics, Philosophy of Technology.

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1 Introduction

Emerging technologies aimed at improving living conditions have gone beyond physical aspects such as biomechanics, cybernetics, robotics and with it, physical extensions of the human body in relation to missing limbs, improving the strength and precision of limbs, improving human muscles (e.g. pacemakers), among other physical advantages that can be observed when integrating hardware technology to the human body and more recently, Artificial Intelligence as the logical engine that establishes the bridge between the human body and the non-human body.

Ruiz Vanoye et al. (2024) describes Artificial Intelligence (AI) as a field of computer science whose foundation is systems capable of performing functions that, prior to their implementation, were performed by humans. The functions that have been integrated into AI are properly those derived from the simulation of learning processes, perception and data collection, logical reasoning, decision making and interaction based on natural language.
AI can be defined as “the ability of a computational system to interpret external data, learn from it and use that knowledge to achieve specific objectives through adaptation and continuous improvement” (Ruiz-Vanoye et al., 2025). Based on this definition, it is possible to identify the relationship that has developed with human welfare, being a recurring theme nowadays, given the integration of emerging technologies aimed at improving the quality of human (and non-human) life.

On the other hand, as mentioned by Fuentes-Penna & González- Ibarra (2024), AI has had an inclusive context, benefiting all people, regardless of their social and economic status. New technologies have taken on an ethical character due to the invasion with respect to the way we think, which implies the debate on the scope they have when incorporated into everyday activities. The purpose of this article is to establish the relationship between Artificial Intelligence and neuromodulation and the incursion of algorithms with neurosciences and neuro-technologies.

2 Neuroscience, Neurotechnology and Neuromodulation

Advances related to neuroscience and neurotechnology open up different possibilities related to access to the human brain and the manipulation, collection and dissemination of data within it. New developments set challenges that, regardless of the reason for their creation, may also present human rights implications that must be addressed to avoid unintended consequences.

2.1 Neuromodulation: Technology and Algorithms

Statistics (INE, 2022) have presented an increase of 3.65% in people with Supervening Brain Injury (SCD) in the period 2008 - 2022, whose main cause is stroke (84%). This type of disease is a limitation for the development of a normal lifestyle and has an associated socio-health impact.

The nervous system has a dynamic function that depends mainly on the supply of oxygen and glucose (Sotero, 2008). When variability is identified in relation to these elements, many disorders can occur, which can currently be solved based on different solutions, such as neuromodulation. With this, the intrinsic neuroplasticity of the nervous system itself can be used, and with the help of natural neuromodulators, the person is neuro rehabilitated.

With new technological advances, neuroplasticity has been complemented by neuromodulation, thus providing tools oriented towards neurorehabilitation as clinical intervention programs.

However, the natural development of solutions has not had a significant evolutionary advance, having the need to create technologies that simulate and, where appropriate, complement human evolution.

Hong and Lieber (2019) have described that neuromodulation consists of altering nervous activity by introducing stimuli. With the actions derived from neuroscience and neurotechnology, different developments related to the brain have been presented that not only allow us to measure and record its activity, but also to manipulate and alter this activity.

Echeverría (2017) describes that neurotechnology is an area that can be oriented towards neuromodulation given that it integrates advances from the areas of systems and microcircuit engineering and that, in turn, has incorporated artificial intelligence, computer sciences and neuroscience, as a disruptive example towards the 4.0 revolution, where biological sciences, physical sciences and digital technologies converge, mainly in this context. In a complementary way, Ausín, Morte and Monasterio Astobiza (2020) have called the areas of convergence as NBIC (for its acronym in Spanish) that integrate nanotechnology, biotechnology, information technology and cognitive science, the latter integrated by Artificial Intelligence, Data Sciences, Robotics, synthetic biology, among others).

The International Neuromodulation Society (Hatzis et al., 2007) defines neuromodulation as the therapeutic alteration of activity in the central, peripheral or autonomic nervous system, whether electrical or pharmacological, by means of implantable devices. Neuromodulation consists mainly in modifying the ion permeability of neurons, either chemically or electrically, for a possible generation of actions by the neurons. This action corresponds to the application of low-frequency electricity to produce an excitation effect. On the contrary, if high frequency electricity is applied, neuronal inhibition can be produced (Machado, Fernandez & Deogaonkar, 2012).

The information obtained from nueromodulation makes it possible to identify the characteristics of the data and with this, to propose solutions in clinical context or simply to satisfy the curiosity of basic science through identifying the way in which data are processed naturally and the signals that are presented during the perception of reality.

According to Medtronic (2025) Neuromodulation is considered as a technology where knowledge related to the nervous system is employed for the development of devices specifically designed as a means of therapy or rehabilitation. With this, different research has been proposed where technical methods, processes and models based on biology have been developed, such as genetic engineering, cellular implants, biochips, among others, for the development of such devices. Thus, interdisciplinarity has combined different areas of research giving rise to neurotechnology, which is based on three main areas:

- Neurodiagnosis consists of analyzing and monitoring the nervous system for the application of effective treatments in the correction of conditions such as seizures, epilepsy, blurred vision, hearing loss, among others.

In this practice, different techniques are used such as neuroimaging, neuroinformatics, in vitro diagnostics, among others (Community Medical Center, 2025).

- The second sector is oriented towards neurodevices that allow neurostimulation to be carried out by means of a neuroprosthesis or, where appropriate, by means of neurosurgery.
- Finally, Neuropharmaceuticals, which Medtronic (2025) divides into cognitive therapeutics, emotherapeutics and senso-therapeutics.

With the proposal of neurodevices based on the fields of neuroscience and nanotechnology, it has been possible to interact with the neuromuscular and sensory system with the purpose of restoring or reducing the impact of a disease or injury in the individual. Currently, implantable or non-implantable devices have been developed as alternatives for the restoration of auditory function, visual function, sensory function and motor function, establishing links through pathological motor or sensory nerve circuits.

From the perspective of Artificial Intelligence, algorithms applied in the field of neuroscience, and especially towards neuromodulation, have been developed that can predict and diagnose neuropsychiatric pathologies. Machine learning models trained to detect early biomarkers of different diseases such as Alzheimer's can be identified, such as the proposal made by Ding et al. (2018) whose foundation is functional magnetic resonance imaging.

Bayona, Bayona Prieto & León-Sarmiento (2011) identified that interventions related to neurorehabilitation increased dramatically in the year 2000derived from the change in the neurological care paradigm, focusing on the regenerative potential of the brain and its dynamic reorganization. This proposed shift gave rise to translational research aimed at improving conditions to enhance brain recovery, deriving in the need for controlled stimulation through neuromodulation and neuronal repair (Barrett et al., 2013).

Neurorehabilitation requires a care process in which it is necessary to identify and define the alterations to guide the phenomena of the intrinsic plasticity of the nervous system and thereby minimize the repercussions, maximize recovery, prevent systemic-neurological complications and improve functional autonomy, whether physical, cognitive or behavioral (Vidalsamsó, 2020).

The incorporation of different branches of scientific knowledge in this field has led to the incorporation of computer science, bioengineering, physics, among other complementary disciplines for the proper application process of neurorehabilitation, with examples such as robotics, brain-machine interfaces and non-invasive and invasive brain and spinal cord stimulation techniques (Ereifej et al., 2021).

An important step in neuromodulation has been telemedicine and therefore telerehabilitation, through the development of platforms with video cameras, remote interaction, among other resources oriented to this process (Mantovani et al., 2020).

On the other hand, according to (Lázara, Reina-Guerra, & Quiben (2020) robotics has been positively integrated into neurorehabilitation and incorporated into neuromodulation. Different devices have been developed and classified as: service robotics, and non-wearables and assistive wearables. These devices can be manual or autonomous and are mainly based on eye and facial recognition, among others, as well as brain-machine interfaces with integrated electroencephalography sensors. With these innovations, when applying the corresponding therapy, the parameters related to strength, resistance and speed applied by the patient are analyzed to elaborate an evolutionary therapy plan and provide feedback to the patient in relation to his or her health condition.

In the case of Artificial Intelligence and its application to neuromodulation, it has been classified as non-invasive based on repetitive transcranial magnetic stimulation or transcranial direct current stimulation. With this convergence between research areas, it has been possible to obtain a large amount of biometric data on both motor and cognitive functions during the development of the patients' therapy, analyzing their evolution.

For this purpose, Artificial Intelligence analyzes the data obtained from the therapies, and such analysis allows automation in the therapeutic management of the patient (precision neurorehabilitation). With this incorporation, feedback can be improved, and the use of machine interfaces can be optimized towards progressive therapeutic benefit (Sadeghi Esfahlani, Butt & Shirvani, 2019).

Particularly, the application of Artificial Intelligence towards neurorehabilitation has been benefited by repetitive interventions of long duration (Maier, Ballester, & Verschure, 2019) and with this, avoiding errors and occupational hazards to the therapist, as well as improving the efficiency of treatments (Dietz & Ward (2015).

The application of Artificial Intelligence has facilitated the integration of robotics and other areas that generate data, so, from its incorporation, a three-step process has been proposed (Avutu & Paul (2022):

- Classify the data obtained
- Predicting fictitious outcomes by regression models, and
- Cluster the results to generate optimal responses to the specific condition.

Other applications of Artificial Intelligence are related to the study of neuroimaging and neurophysiological tests, which facilitate the development of functional and temporal prognoses in complex scenarios such as altered states of consciousness (Kondziella et al., 2020).

As part of the development of artificial intelligence tools, solutions based on neuromodulation have been implemented, as is the case of artificial neural networks that have adopted algorithms that simulate this process.

Daram, Kudithipudi & Yanguas-Gil (2019) proposed to incorporate neuromodulation by proposing an architecture called ModNet (modulatory network) that is based, from this perspective, on the neuro-modulatory mechanism of the human brain oriented to learning mechanisms that influence synaptic plasticity, neuronal wiring and mechanisms of long-term potentiation and long-term depression (Figure 1.

On the other hand, Carew, Walters & Kandel (1981) conducted studies in mollusks where they have identified a relationship between the neuro-modulatory mechanism with associative learning and synaptic changes.

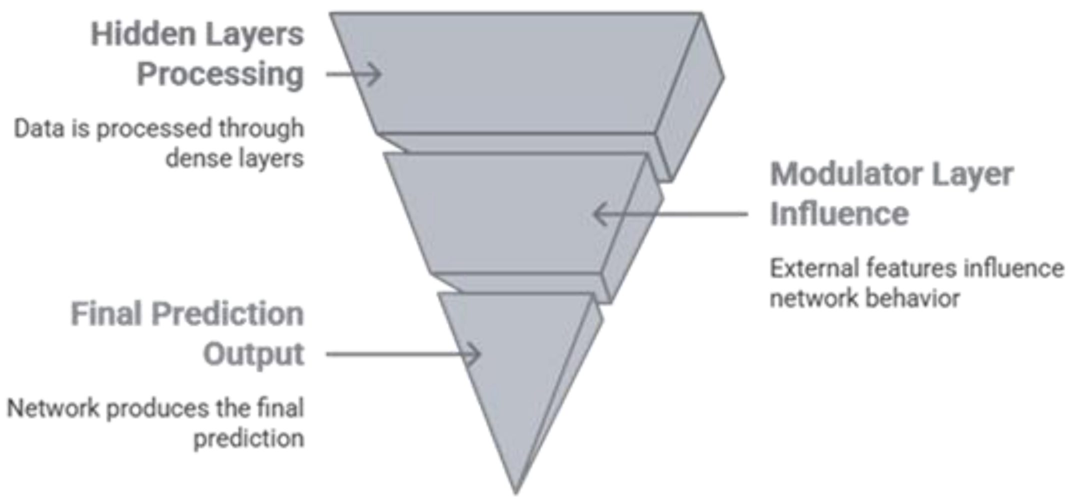

Figura 1. An additional modulator layer in neural networks.

The proposal by Daram, Kudithipudi & Yanguas-Gil (2019) presents a network with two units:

- Processing unit focused on learning distinctive features and representations, for spatial feature extraction, and
- Neuromodulatory layer focused on context learning, which compensates for learning error by regulating trainable weight (equations 1 - 6).

$$A_i = Sigmoid(\sum w_{ij}x_j) \quad (1)$$

$$M_i = \sum w'_{ij}x'_j \quad (2)$$

$$\Delta w_{ij} = Sigmoid(\frac{M_i}{n_{ij}}) x \delta_{ij} \quad (3)$$

$$\delta_{ij} = \eta_{ij}(\beta_1 x_i x_j + \beta_2(x_j - x_i) + \beta_3) \quad (4)$$

$$\eta_{ij} = \eta_{in} \frac{e_i}{x_i} \quad (5)$$

$$\Delta w'_{ij} = n'_{ij}(scale) \quad (6)$$

Where:

- w_{ij} Weight of the hidden layer to the output layer
- xj Hidden layer presynaptic activations.
- n_{ij} Adjustable scale parameters in training.
- δ_{ij} Plasticity
- x_j Postsynaptic activations
- β_1, β_2 y β_3 Adjustable network parameters.
- η_{in} Initial value of the learning rate
- e_i Error in output neuron observed.

This approach combines synaptic local learning rules with error-based modulation during the learning process at the boundary.

Vecoven et al. (2020) mention that the adaptive capacity of biological nervous systems is directly linked to neuromodulation to adjust the functionality of neural networks and regulates their input/output behavior based on external stimuli. The authors present a neural architecture called NMN (Neuro Modulated Network), which is formed by two neural networks:

- Main network (transition neural network): parametric activation neurons with neuromodulation parameters.
- Neuromodulatory network controls the neural properties of the main network based on activation parameters.

This architecture is based on the interaction between the neuromodulatory network with the main network through the action of neuromodulation and the preprogrammed bias of the activation function in the main network.

Neuromodulation, combined with advances in artificial intelligence (AI), represents a promising frontier in the field of neuroscience, medicine and cognitive technology. Among the main advantages of this integration are the personalization of neurological treatments, increased precision in brain interventions, improved quality of life in people with neurological or psychiatric disorders, and the potential to optimize human cognitive functions. AI can analyze large volumes of neural data in real time, facilitating faster and more effective clinical decisions.

However, there are also significant disadvantages that should not be overlooked. These include ethical concerns about manipulating the human brain, risks to patient privacy and autonomy, inequalities in access to these technologies, and possible adverse effects not yet fully understood. In addition, reliance on algorithmic systems raises dilemmas about automated decision making in sensitive contexts.

In this context, the future of neuromodulation with AI presents itself as fertile but uncertain ground. While there is great transformative potential, there are also numerous technical, ethical, social and legal challenges to be resolved. Therefore, its evolution will depend on both scientific progress and the responsibility with which these technologies are implemented for the benefit of humanity.

2 Conclusions

The inclusion of new technologies and in particular of Artificial Intelligence in the field of neuromodulation has been well accepted, however, negative evaluations have been observed since these techniques lacked flexibility and therapeutic potential given that personalized data and training time are required, which implies having an individualized cognitive therapy that can be based on data that are not totally real due to the predisposition towards the creation of synthetic data.

The need to establish strategies to overcome barriers and uncertainties that limit innovation, and the obligation to make correct and safe use of data to optimize the care process with these tools.

In conclusion, it is up to neurorehabilitation specialists to recognize the benefits of Artificial Intelligence, as well as to continue promoting its research and clinical, direct and early application, both diagnostically and therapeutically.

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