KRRISH SCIENTIFIC PUBLICATIONS

Journal of Computing and Data Technology

https://journal.krrishpub.com/index.php/jcdt/index

ISSN: 3107-9466

Bridging Mind and Machine: Enhancing Human Potential Through Self Regulation and Brain-Computer Interfaces

Mohammad Parhamfar [a,*], Milad Taheri [b,c], Zahir Bandegani [d], Ghita Lazrek [e], Hajar Fares [f]

[a] *Independent Researcher and Entrepreneur, Iran*
[b] *Department of Electrical Engineering, Islamic Azad University, Najafabad, Esfahan, Iran.*
[c] *Safahan Institute of Higher Education, Isfahan, Iran.*
[d] *Independent Researcher, Isfahan. Iran.*
[e] *Lab LIASSE, École Nationale des Sciences Appliquées de Fès, Sidi Mohamed Ben Abdellah University (USMBA), Fez, 93000, Morocco.*
[f] *Faculty of Sciences, Abdelmalek Essaadi University, Tetouan, 93000, Morocco.*

Abstract

In an era defined by accelerating neurotechnological innovation and heightened cognitive demands, the pursuit of human enhancement is reaching unprecedented heights. This paper explores two converging frontiers of optimization: internal strategies of mind management and external augmentation via brain-computer interfaces (BCIs). Drawing from recent empirical research, mathematical models, and startup ecosystems, also analyzed how self-regulation techniques such as mindfulness, reframing, and attentional training intersect with emerging neurotechnology to expand cognitive capacity, productivity, and mental wellbeing. Clinical applications of BCIs, including Deep Brain Stimulation (DBS) and Responsive Neurostimulation (RNS), are evaluated alongside non-invasive wearables, with comparative insights into efficacy and patient outcomes. Furthermore, the study examines advanced BCI architectures, ethical dilemmas in military and defense applications, and emerging strategies within the commercial neurotechnology market. In parallel, mathematical optimization frameworks and neuro-algorithmic models are presented to bridge the disciplines of neuroscience and artificial intelligence, highlighting their synergistic potential for cognitive enhancement. By synthesizing interdisciplinary insights, the paper outlines future research directions and offers a critical roadmap for responsible innovation in the medical and business sectors. Ultimately, this study positions the integration of self-directed mental practices and neurotechnological tools as a dual engine for unlocking human potential.

Keywords: Brain-Computer Interfaces (BCIs) ,Cognitive enhancement ,Neurotechnology ,Neuroleptics,Human-Machine Integration.

Article Information:
DOI: https://doi.org/10.71426/jcdt.v1.i2.pp77-90
Received: *29 September 2025* | Revised: *15 November 2025* | Accepted: *21 November 2025*

1. Introduction

1.1. The dual frontiers of human potential

Maximizing human potential, particularly regarding productivity and cognitive performance, has long been a subject of intense inquiry [1]. Throughout the ongoing pursuit to harness the full potential of the human mind, emphasis has traditionally been placed on internally regulated, self-directed methodologies collectively known as the art and science of mind management. These conventional strategies prioritize the cultivation of conscious control over cognitive and emotional processes to optimize mental efficiency, stimulate creativity, and enhance overall wellbeing. However, as anyone who has battled procrastination, distraction, or negative self-talk is aware, an unmanaged mind can also lead to dysfunction and distress, which can undermine happiness and productivity. The enormous difficulty of preserving mental equilibrium is demonstrated by the sheer volume of everyday thoughts, which are frequently estimated to be in the tens of thousands. A poorly controlled mind is ineffective and can seriously impede one's ability to accomplish their objectives. Motivation is often depleted by mind-numbing emotional dysregulation and lack of focus, making sustained effort a pipe dream rather than a reality [2].

*Corresponding author
Email address: drparhamfar@gmail.com (Mohammad Parhamfar), milad.taheri@iau.ir, m.taheri@Safahan.ac.ir (Milad Taheri), z.bandegani@hotmail.com, z.bandegani@hotmail.com (Zahir Bandegani), lazrekghita@gmail.com, ghita.lazrek@usmba.ac.ma (Ghita Lazrek), hajar.fares@etu.uae.ac.ma, hajar.fares@etu.uae.ac.ma (Hajar Fares).

Therefore, a mindful approach the capacity to observe thoughts and feelings without passing judgment, identify patterns, and consciously substitute more constructive viewpoints for negative ones is necessary for effective mind management. Despite their effectiveness, these methods still require self-control and internal work. However, what if external technologies could amplify this process, offering new pathways to manage and enhance the mind? Humanity is now on the cusp of a new era where BCIs and electronic chips offer the unprecedented potential to directly modulate and enhance brain function. What was once the stuff of science fiction is becoming increasingly tangible. BCIs allow the brain to communicate directly with external devices, bypassing traditional pathways like muscles or speech. In the last few years, companies like Neuralink and research groups worldwide have made significant strides in making BCIs a reality. A future where the lines between artificial intelligence and human cognition are blurred is being ushered in by Neuralink's successful trials in 2024, which showed the promise of mind-controlled devices allowing users to play video games with just their thoughts [3]. These neurotechnological advancements are not just about futuristic enhancements; they are also paving the way for therapeutic applications that could revolutionize the treatment of neurological conditions. For example, DBS and BCIs are already helping patients with Parkinson's disease, chronic pain, and epilepsy regain motor function and control. However, the goal goes beyond rehabilitation; neuro-enhancement is in the works. Soon, the idea of enhancing cognitive, memory, and focus skills could become a reality, giving people access to superhuman abilities [4]. One such objective is to improve cognitive function and data-processing abilities to a level that is noticeably superior to what is currently achievable for humans through the utilization of nanotechnology in advancing BCI. The rapid global growth of data processing and the challenge of human cognitive constraints are the main drivers of this drive. As technologies like quantum computing and silicon-based chips push forward, the comparison between human intelligence and artificial intelligence becomes increasingly relevant, challenging our understanding of consciousness, intuition, and sense qualities that the human brain uniquely possesses and that machines are still far from replicating [5]. The ethical and societal ramifications of the rapid synthesis of mind and machine are increasing. What would happen if BCIs could be used to change our thoughts, filter our emotions, or communicate telepathically? Such developments have the potential to be both promising and dangerous. Privacy, autonomy, and inequality loom large, as neurotechnology could create a new divide between those with access to enhancements [6].

This paper explores both frontiers: mind management techniques and the emerging realm of neurotechnology. The role of conventional approaches to mental resource optimization will be examined as a foundational pillar for productivity alongside the transformative potential of neurotechnological cognitive enhancement. A detailed analysisof the current and prospective applications of BCIs will be conducted, assessing their therapeutic uses and capacity to augment cognitive functions. Ethical considerations will also be critically evaluated, particularly concerning privacy, autonomy, and patient safety. Ultimately, the intersection of these dual frontiers will be explored to understand how they may collectively shape the future of human enhancement, with an emphasis on pursuing innovation responsibly and in alignment with the broader interests of humanity [7]. BCIs can serve as advanced control interfaces between humans and smart energy systems. In renewable energy grids (e.g., solar or wind farms), human operators can use BCIs to monitor and adjust system parameters hands-free, enabling faster and more intuitive control of distributed energy resources, especially in critical situations such as grid instability or rapid load fluctuations. For this topic, some renewable energy articles that researchers have reviewed are recommended [8] - [11].

1.2. Research objectives

This paper investigates how AI tools and cloud storage systems contribute to the enhancement of startup businesses. Specifically, it aims to:

i. Identify key Artificial Intelligence (AI) and cloud technologies adopted by startups.
ii. Examine the impact of AI and cloud technologies on business processes, decision-making, and customer engagement.
iii. Propose a systematic methodology for the effective integration of AI and cloud technologies in startup ecosystems.
iv. Evaluate relevant case studies to demonstrate the tangible benefits achieved through AI and cloud adoption.
v. Highlight the key challenges associated with AI and cloud implementation and propose directions for future research.

1.3. Structure of the manuscript

The remainder of this paper is organized as follows: Section 2 provides a comprehensive literature survey. Section 3 outlines the methodology. Section 4 presents results and discussion, including case studies and comparisons. Section 5 concludes the study with insights and recommendations.

2. The inner frontier: Mind management for innate productive potential

AI Before contemplating external enhancements, it is critical to acknowledge the significant potential for improvement that can be attained through focused mental control [12]. This internal strategy uses psychological abilities that enable people to maximize their emotional and cognitive capacities [13]. To achieve greater happiness, calm, and focus, mind management involves a thoughtful and competent relationship with one's thoughts and feelings rather than just relieving stress or having an "empty mind" [14].

2.1. The mind: asset and obstacle to productivity

An individual's brain is a fantastic tool that can solve problems, learn new things, and be incredibly creative. However, the main barrier to productivity may be an uncontrolled mind. This frequently results in severe dysfunction and distress, which affects general well-being and productivity at work [13]. Distraction and mind-wandering

Table 1: Real neurotechnology startup landscape.

Startup name	Country	Focus area	Core product / service	Funding	Innovation angle
Neuralink	USA	Invasive brain–computer interfaces	High-bandwidth, fully implantable and wireless brain–computer interface systems enabling neural signal recording and stimulation	$363M+	Ultra-high channel-count neural implants with robotic surgical precision
NextMind	France/USA	Non-invasive BCIs	Brain-sensing wearable platform enabling intent-based control of digital interfaces using visual cortex signals	Acquired	Real-time decoding of visual attention and neural intent
Emotiv	USA	Neurofeedback and EEG	Portable EEG headsets for neuroscience research, wellness monitoring, and cognitive training applications	$10M+	Affordable, consumer-grade EEG with cloud-based analytics
Kernel	USA	Brain activity mapping	Kernel Flow wearable for non-invasive measurement of cognitive states using optical neuroimaging	$100M+	Real-time functional brain monitoring using time-domain fNIRS
Neurable	USA	BCI for AR/VR	EEG-integrated headphones enabling mental state tracking and hands-free interaction in immersive environments	$13M+	Seamless integration of neural signals into consumer AR/VR platforms

are common mental culprits that often fragment attention and make sustained effort difficult [14]. Procrastination, often driven by fear of failure, perfectionism, or feeling overwhelmed, is a classic symptom of a mind struggling to engage with or regulate its response to a task. Internal dialogues filled with self-doubt, criticism, or catastrophizing, known as negative self-talk and limiting beliefs, can sap motivation, erode confidence, and create self-fulfilling prophecies of underperformance [14]. Furthermore, unmanaged stress, anxiety, or frustration can lead to emotional dysregulation, clouding judgment, impairing decision-making, and depleting the mental energy required for productive work [15]. Without defined objectives and priorities, mental energy becomes dispersed, leading to activity without real achievement. Understanding these typical pitfalls is the first step to successfully addressing them [12].

2.2. Core pillars of mind management for enhanced productivity

Developing a more aware and adept relationship with thoughts and emotions is the key to effective mind management, not repressing them. The pillars below offer a strong foundation for increasing productivity [14].

2.2.1. Cultivating self-awareness

The cornerstone of mind management is self-awareness, which entails paying close attention to one's thoughts, feelings, and behavior patterns without passing judgment immediately. People can gain the insight necessary for change by engaging in practices like mindfulness meditation, which allows them to observe their psychological conditions without passing judgment[14]. Journaling provides a thoughtful way to examine everyday events, stressors, and emotions, identifying trends and opportunities for development, and frequently stopping during the day to inquire, "What am I thinking? How do I feel? Self-awareness can be further improved by asking, "Where is my attention?" [15].

2.2.2. Setting clear intentions and goals

A well-directed mind is more likely to allocate its resources efficiently and is less likely to become distracted. Specific, attainable, quantifiable, relevant, and time-bound SMART goals offer direction and clarity. Setting one or three main goals at the beginning of each day helps concentrate mental energy on the things that matter, and prioritization frameworks can direct attention to important tasks [16].

2.2.3. Mastering focus and attention

Deep concentration is a superpower in today's attention economy. Refusing to multitask frequently results in worse quality and more stress. The Pomodoro Technique, which includes setting aside specified blocks of time for concentrated work interspersed with brief breaks and time blocking, are two strategies that can improve focus and avoid burnout. It is also critical to reduce distractions by setting up a workspace that supports concentration, such as shutting down tabs that are not needed and turning off notifications [16].

2.2.4. Reframing negative thoughts and beliefs

Our emotional reactions and subsequent actions are frequently determined by how an individual interprets events rather than the events themselves. By using cognitive restructuring techniques, people can recognize, question, and swap out harmful or unproductive thought patterns for more sensible and productive ones [15]. Practicing gratitude can combat negativity and increase resilience by focusing on the good things in life and at work. Over time, limiting beliefs can be rewired by deliberately repeating positive affirmations concerning the individual and their abilities [16].

2.2.5. Building resilient and productive habits

Much of our daily behavior is driven by habit, making cultivating productive habits essential for automating success. Habit stacking, which involves linking a new desired habit to an existing one (e.g., "After my morning coffee, I will spend 15 minutes planning my day"), can facilitate integration [13]. Starting small and breaking down significant goals into manageable habits makes them less daunting and easier to integrate into daily routines. Consistency over intensity, meaning regular, consistent effort even in small doses, compounds over time to yield significant results [16].

2.2.6. Managing mental energy

Effective time management is only one aspect of productivity; another is critical mental and emotional energy management. Sleep is essential for memory consolidation, emotional control, and cognitive function [16]. Taking thoughtful, brief breaks during the working day can help an individual stay focused and avoid mental exhaustion. A healthy, resilient mind is also strongly supported by maintaining physical health through consistent exercise and a healthy diet [13].

2.3. Integrating mind management into daily life

Developing practical mind management skills is a continuous process rather than a quick fix. Patience, self compassion, and a dedication to lifelong learning and adaptation are necessary. Instead of completely overhauling everything at once, people should initially select one or two techniques to practice. Since it demands time and effort to change deeply rooted thought patterns, it is critical to recognize any progress, no matter how tiny. It is crucial to try various methods and modify them to fit individual preferences and situations because what suits one person might not suit another. Seeking assistance from coaches, mentors, or peers can offer insightful information and accountability [17].

3. The technological frontier: Electronic chips for brain function management and enhancement

In addition to self-regulation, neurotechnology can directly interact with the brain to control and improve its operations. The BCIs and electronic chips are the primary methods used in this field [18]. Bypassing conventional channels like speech or muscles, brain-machine interfaces, or BCIs allow direct communication between the brain

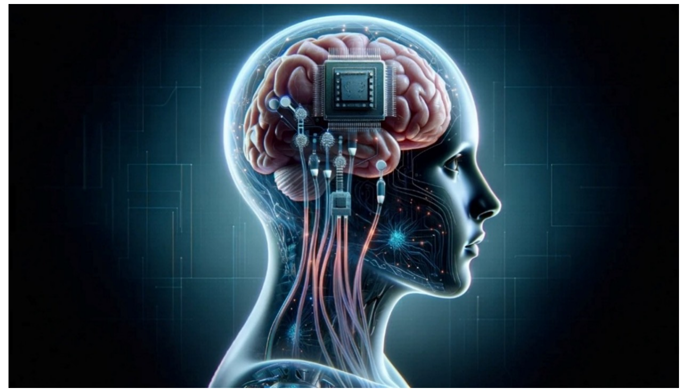

Figure 1: Neuralink BCI implant for human-machine integration [20].

and external devices. They decipher neural signals and convert them into commands that computers, prosthetics, and other devices can follow. A sensor that detects neural signals, an operating system that runs an algorithm that decodes the signals, and a source of output that changes based on the application are usually the main parts of BCI systems [19]. Recent trials with Neuralink implants exemplify how electronic chips can be embedded directly into the brain, enabling high-bandwidth brain-machine interfaces and paving the way for enhanced cognitive and physical functions, as illustrated in Figure. 1.

The conceptualization of the brain as a "biological computer" with "mushy hardware and software evolving from life experiences" has long underpinned efforts to create artificial intelligence. Historically, the exponential growth in chip processing power, famously predicted by Moore's Law, has seen transistor density on chips increase dramatically. This makes comparing human and artificial intelligence increasingly relevant [21]. While computer chips are often called the "brain of a computer," performing logical results based on predefined instructions and controlling peripherals, the human brain controls vital bodily activities such as breathing, heartbeat, and temperature regulation. Both systems require energy to function, with chips needing electricity and the brain requires oxygen and sugar [22]. They can perform calculations and logical tasks and use electrical signals to transmit information [21]. However, crucial differences persist: the human brain is a biological system that is parallel, distributed, fault-tolerant,learns, and possesses inherent "sense," "intuition," and "consciousness," which computer chips, functioning on preprogrammed logic, currently lack. Unlike a CPU, the brain can also partially recover from damage, which typically ceases functioning if any part is damaged. Despite advancements like quantum computing and silicon-based qubits promising significantly increased computational power, the human brain still holds supremacy in its overall processing power and intuitive capabilities [22], shown in Figure 2. This symbolic image illustrates how BCIs act as a bridge between biological cognition and electronic systems, a foundational concept for modern neurotechnology.

3.1. Therapeutic application: A clinical deep div

The most clinically validated and impactful neurotechnology applications are found in therapeutic contexts, targeting debilitating neurological disorders. The DBS, a well-established surgical intervention, involves implanting electrodes in specific subcortical structures to deliver modulated electrical impulses [7]. Its efficacy has been well documented in alleviating motor symptoms associated with Parkinson's disease, dystonia, and essential tremor, with ongoing trials extending to treatment-resistant depression and OCD [24]. Modern advancements, such as closed-loop DBS, now enable real-time feedback systems that dynamically adjust to stimulation, improving outcomes and reducing side effects. Responsive neurostimulation systems extend therapeutic potential, particularly in epilepsy care. These implantable devices monitor brain activity and deliver targeted stimulation upon detecting abnormal patterns, preventing seizure propagation [25]. This personalized neurostimulation marks a shift from reactive to anticipatory intervention models in neurology. Figure 3 compares the clinical effectiveness of BCI therapies (DBS, RNS) with traditional approaches, such as medication or physical therapy, across neurological conditions like epilepsy and Parkinson's disease. Moreover, BCIs are transforming care pathways for individuals with paralysis or severe communication impairments. Emerging technologies like Neuralink's N1 interface, featuring high-density, flexible threads embedded with electrodes, offer avenues for restoring volitional control over digital devices or assistive robotics via neural intention decoding [26]. These advancements redefine neurorehabilitation by combining surgical precision, AI-based decoding, and neuroplasticity-driven therapy.

i. Risks and Protocols: As these technologies become more integrated into clinical routines, new protocols are needed to monitor adverse effects such as infection, device migration, or neuropsychiatric responses. Ethical concerns must also be addressed, particularly regarding patient autonomy, consent in vulnerable populations, and the long-term psychological effects of implanted interfaces. iPathways and Integration: Future care models will likely combine pharmacological, psychological, and neurotechnological therapies. Interdisciplinary teams of neurologists, bioethicists, and neuroengineers must collaboratively define patient eligibility criteria, post-op monitoring frameworks, and upgrade paths for implanted systems.

3.2. Potential for cognitive enhancement

While primarily in nascent or research stages, the technology used for therapy also hints at future applications for cognitive enhancement in healthy individuals. Targeted neurostimulation or BCIs could help sustain attention, filter distractions, or induce states conducive to deep work [22]. The potential of electrical stimulation to speed up learning or strengthen memories is being actively investigated in research. Subtle mood modulation has the potential to improve resilience and motivation in addition to treating conditions like depression [27]. These applications increase the likelihood of "managing" brain states more successfully than psychological techniques by offering shortcuts or extra assistance to internal mind management. Additionally, these advancements aim to create brain chips using nanotechnology to make people "superhumans" in response to the difficulty of quickly processing large amounts of data [27].

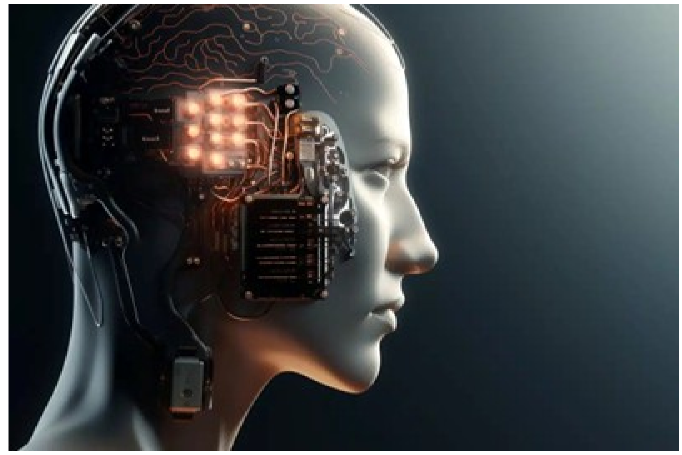

Figure 2: Conceptual fusion of brain activity with computing systems [23].

3.3. Advanced BCI mechanisms and applications

Increasingly sophisticated mechanisms and diverse applications mark the evolution of BCIs. The technology builds Electroencephalography (EEG) principles to record and interpret brain signals [28]. This converts electrical signals from brain nerve cells into digital data. Key components of a BCI system include an implanted chip on a pedestal, fiber optic cables, and a neural signal interpreter that converts brain activity into digital signals and vice versa. This allows computers to "mimic all the functions of brain activities" and control external devices based on thought [29]. An important turning point in neurotechnology was reached in 2024 with Neuralink's first human implant, which was followed by later innovations like the Blindsight implant for perception restoration. As evidenced by initial human trials in which patients could operate a computer and play video games with just their thoughts, this development enables human subjects to manipulate computer programs exclusively with their thoughts [30]. The integration of AI has further amplified the power and potential of BCIs, offering increased speed and accuracy in decoding neural signals. This leads to more finely tuned prosthetic movements and enriching stimulation during bidirectional communication with the brain. Future BCIs could even simulate virtual realities and dreamscapes, raising profound existential questions about the definition of reality [30]. Figure 4 is a non-invasive BCI applied to the hand that represents practical implementations for neurofeedback and mental state monitoring without surgical procedures.

3.3.1. Optimization algorithms in neurotechnology: Enhancing performance and precision

In neurotechnology, particularly in Brain-Computer Interface (BCI) systems, optimization algorithms play a

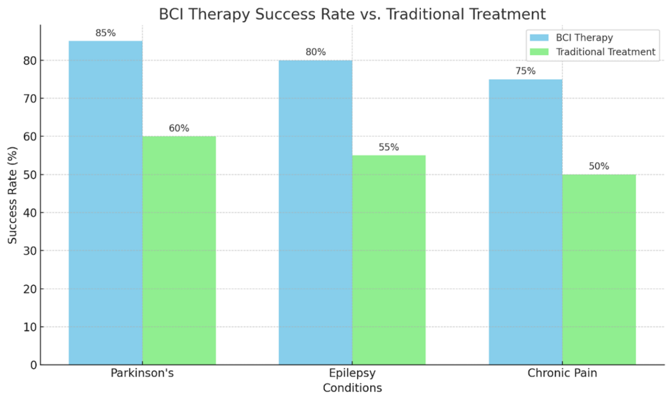

Figure 3: BCI therapy vs. traditional treatment outcomes.

pivotal role in enhancing accuracy, speed, and adaptability. From tuning decoding parameters in real-time to improving user-specific calibration, these algorithms serve as the mathematical core of adaptive, intelligent BCIs. Techniques such as Particle Swarm Optimization (PSO), Genetic Algorithms (GA), and Differential Evolution (DE) are widely adopted to refine signal classification, minimize error rates, and personalize control systems. The table below provides a comparative overview of prominent optimization methods used in neurotechnology, highlighting their applications, strengths, and limitations within BCI and neurorehabilitation contexts [28], [30].

3.4. Wearable and non-invasive neurotechnology for cognitive and emotional management

Beyond invasive implants and sophisticated BCI systems, the technological frontier extends to wearable and non-invasive neurotechnology designed for direct cognitive and emotional management. A notable recent development in this area is the advent of electronic tattoos engineered to monitor psychological stress and potential burnout. This innovative, temporary, wireless electronic tattoo is designed to be placed on the forehead, discreetly decoding brainwaves to measure mental strain without requiring cumbersome head coverings [32]. The electronic tattoo operates using a lightweight battery and paper-thin sensors, featuring wavy loops and coils that stretch and conform precisely to the skin, thus ensuring a clearer neural signal acquisition [33]. It analyzes the electrical activity from the brain and eye movement through EEG and electrooculography (EOG). Unlike bulky EEG caps that require conductive gels, this wireless e-tattoo consists of a lightweight battery pack and paper-thin, sticker-like sensors, offering enhanced comfort and clear signals due to its seamless skin conformity. Furthermore, this device is made to be economical; its chips and battery pack cost about $200, and each disposable sensor costs about $20. This makes it a far more cost-effective option than traditional EEG equipment [33]. A crucial aspect of this technology is its integration with artificial intelligence (AI). Researchers have trained a computer model to accurately estimate mental workload based on the signals received from the e-tattoo [33]. This AI offers a proactive tool for managing mental well-being and anticipating mental fatigue because it can differentiate between

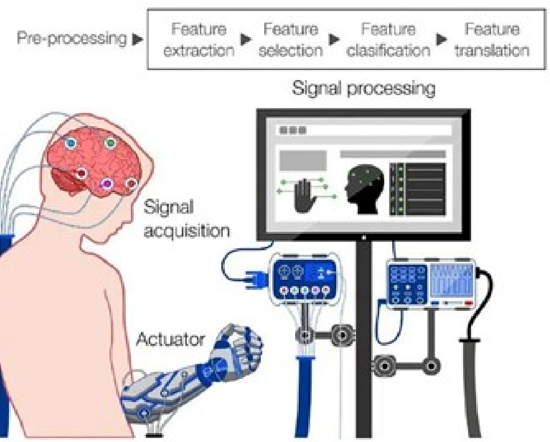

Figure 4: Wearable BCI device for cognitive enhancement [31]. BCI signal pathway mapping and routing.

Figure 5: Wearable neurotech for mental health monitoring [35].

different levels of mental workload and predict when the brain is likely to become overwhelmed. Current versions are mainly made for skin without hair, but research is being done to apply ink-based sensors to hairy scalps so that more thorough brain monitoring is possible. The ability of people to practice mind management, especially developing self-awareness and maximizing mental energy, could be significantly improved by such non-invasive predictive tools. However, they also raise new discussions regarding continuous personal data monitoring and privacy [34]. Wearable sensors like smartwatches are shown in Figure 5. These tools offer non-invasive stress and attention monitoring tools, supporting personalized emotional management and well-being.

4. Neurotechnological frontiers in defense: Enhancing soldier capabilities and the ethical quagmire

While the paper outlines the therapeutic promise and potential for general cognitive enhancement through neu-

Table 2: Comparison of neurotechnology optimization algorithms.

Algorithm	Application	Advantages	Limitations
Particle Swarm Optimization (PSO)	Feature selection and classification in EEG/BCI systems	Simple to implement with faster convergence	Prone to getting stuck in local optima
Genetic Algorithm (GA)	Optimizing signal classification and control accuracy	Suitable for global search and adaptable to diverse problems	Computationally expensive with slow convergence
Differential Evolution (DE)	Real-time parameter tuning in adaptive BCIs	Robust with few parameters; suitable for continuous optimization	Less effective for discrete optimization problems
Simulated Annealing (SA)	Electrode placement and noise reduction	Effective in avoiding local minima	Slow convergence and sensitivity to initial parameters
Ant Colony Optimization (ACO)	BCI signal pathway mapping and routing	Effective for combinatorial optimization problems	Performance degrades with large solution spaces
Bayesian Optimization	Hyperparameter tuning in deep BCI models	Efficient for expensive-to-evaluate objective functions	Requires probabilistic model assumptions

Figure 6: Soldiers using AR goggles in combat scenarios [37].

rotechnology like BCIs, a significant and ethically charged application domain lies in the military and defense sector. The prospect of 'enhancing soldier capabilities' represents a paradigm shift in military science, moving beyond traditional equipment to direct augmentation of the warfighter [36]. Figure. 6 illustrates that neurotechnology is increasingly integrated into defense systems, with AR tools enhancing situational awareness and communication in high-stress military environments.

4.1. Cognitive and perceptual augmentation

Military settings directly relate to the paper's discussion of BCIs for "sustaining attention, filtering distractions, increasing learning processes, and delicate mood modulation." The neurotechnology may help soldiers perform at their best and remain vigilant and focused for extended periods or under high stress, reducing the possibility of human error [38]. They could also achieve accelerated skill acquisition, rapidly learning to operate complex new weapon systems or adapt to novel tactical environments, reducing training pipelines. Enhanced situational awareness is another potential benefit, as BCIs integrated with sensor data and AI could help soldiers process vast amounts of battlefield information [39]. This offers an intuitive understanding of complex, dynamic environments akin to the envisioned superhuman processing capabilities. Neurotechnological interventions may also improve mental toughness in battle, regulate stress and emotions, or alter fear reactions. This presents serious ethical issues regarding potential desensitization and overriding human reactions. The real-time physiological tracking of soldiers could be adapted from the non-invasive 'electronic tattoo' concept for stress monitoring, which gives commanders information on individual distress or unit readiness [39].

4.2. Advanced communication and control systems

The advanced communication and control systems could enable covert and secure communication, facilitating silent, encrypted, thought-based communication between squad members, making them less detectable. Direct Neural Interface (DNI) for equipment represents another frontier [40]. Beyond 'remote-controlled animals,' soldiers could potentially control drones, uncrewed ground vehicles, cyber warfare tools, or even sophisticated weapon systems with unparalleled speed and precision through direct neural commands. This echoes the capability of Neuralink's trial subjects to control computers with their minds [25]. While focused on individual enhancement, AIpowered battlefield information [40].

4.3. The 'super-soldier' and the neuro-arms race

The objective of converting human beings into "superhumans" through the application of nanotechnology in brain chip development inevitably leads to the concept of the 'super-soldier.' This pursuit could trigger a neuro-arms race, where nations compete to develop superior neurologically enhanced warfighters, leading to geopolitical instability and an escalation of military capabilities [41]. Figure. 7. visually represents the emerging "super-soldier" paradigm, where soldiers equipped with BCIs can operate military tools directly through neural commands, illustrating neuro-enhancement's ethical and geopolitical stakes.

The ethical issues raised in the paper, privacy, autonomy, societal impact, and patient safety, are magnified in a

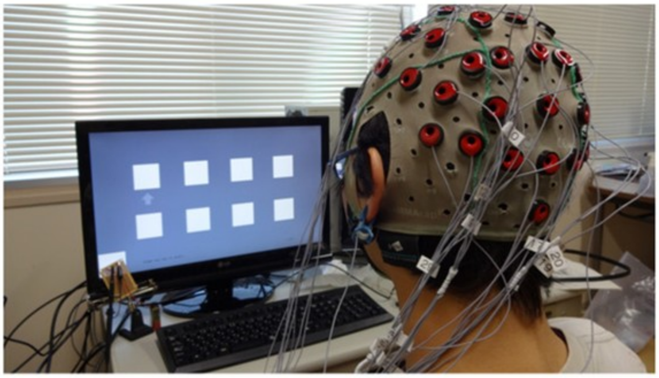

Figure 7: BCI-enhanced soldier operating defense systems [42]

military setting [43]. Concerns about coercion and autonomy are raised: Will there be covert coercion, or can soldiers agree to invasive neurotechnologies? What happens to a soldier whose mental processes or behavior are controlled or influenced by a brain-computer interface (BCI)? A clear reminder is provided by the 'Robo-rat' experiment [43]. Responsibility and accountability also become complex: Who is responsible for actions taken by a BCI-enhanced soldier, notably if the BCI malfunctions or is hacked? Furthermore, concerns about dehumanization arise, as direct neural manipulation for combat effectiveness risks dehumanizing soldiers, turning them into mere extensions of weaponry. Finally, security and 'neuro-hacking' become paramount: BCIs in soldiers would become high-value targets for adversaries, with the potential for neural data theft, manipulation, or incapacitation through cyber-attacks [44].

Integrating neurotechnology into military applications presents a dual frontier: one of unprecedented capability enhancement and another of profound ethical, legal, and strategic challenges. While pursuing technological superiority is a constant in military history, the direct interface with the human mind demands an even more cautious and ethically rigorous approach than any previous military technology, reinforcing the paper's call for 'responsible technological innovation' on a global scale.

5. Improve business by optimizing employee performance, focus, and well-being

Economics is fundamental to young people today, especially Generation Z, and this technology can lead entrepreneurs to this idea [45],[46]. Personalized training through BCIs can revolutionize employee development.Training programs can adapt in real-time to optimize learning by monitoring brain activity. This ensures employees grasp concepts faster and more effectively, maximizing knowledge retention. Imagine tailored modules focusing on areas needing improvement, identified through neural feedback. This targeted approach minimizes wasted time and resources, leading to a more skilled and efficient workforce. Furthermore, personalized training can cater to diverse learning styles, fostering a more inclusive and engaging environment. Ultimately, this leads to increased productivity, job satisfaction, and a more potent competitive edge for the business. The core innovative idea is integrating neurotechnology with mind management techniques to enhance human capabilities. Here are three startup ideas on how it can improve business:

i. Neuro-enhanced Productivity Training: A startup offering personalized training programs using neurofeedback to improve focus, reduce stress, and increase employee productivity.
ii. Brain-Computer Interface Learning Platform: Using brain-computer interfaces to adapt real-time training content, optimizing knowledge retention and skill development.
iii. Mental Wellness Monitoring for Businesses: A wearable neurotech service to monitor employee mental wellbeing, providing data-driven insights to companies for proactive interventions and support.

5.1. Emerging Neurotechnology startups: bridging innovation and human enhancement

The neurotechnology startup landscape is transforming, fueled by an influx of venture capital and breakthrough innovations in BCIs systems [47]. In 2024 alone, investments in neurotechnology exceeded $2 billion, signaling growing confidence in the sector's therapeutic and commercial potential. Leading companies like Neuralink and Synchron are pioneering invasive and minimally invasive BCIs, respectively, to restore motor and communication functions in individuals with neurological impairments. Meanwhile, startups like Precision Neuroscience and Paradromics are developing scalable neural interfaces targeting clinical and consumer markets. This surge in innovation reflects a broader societal shift toward integrating artificial intelligence and neural data for enhanced human performance and well-being [48]. As the market matures, these ventures are redefining the frontiers of cognitive augmentation and shaping the ethical and regulatory frameworks that will govern future human-machine symbiosis [47].

5.2. Mathematical foundations of neuro-AI optimization

BCIs and neurotechnology evolve deeply on mathematical models that enable data interpretation, signal decoding, and system performance optimization. Foundational mathematical tools such as differential equations, linear algebra, and Fourier transforms are employed in signal processing to extract meaningful neural features from EEG or implant data. Meanwhile, artificial intelligence, particularly in neural signal classification and brain-state prediction, relies on advanced optimization algorithms like gradient descent, evolutionary algorithms, and convex programming to train and refine models [51]. For instance, Bayesian optimization (BO) is increasingly used to calibrate BCI parameters in real-time with limited data, enhancing adaptability and user-specific accuracy. As the complexity of neuro-AI systems increases, integrating reinforcement learning and variational inference has become central to modeling dynamic and uncertain brain responses. These mathematically grounded approaches improve algorithmic performance and enhance the interpretability and robustness of neurotechnological systems across clinical, military, and cognitive enhancement domains [49],[50]. In recent years,

Table 3: Real neurotechnology startup landscape.

Startup name	Country	Focus area	Core product / service	Funding	Innovation angle
Neuralink	USA	Invasive brain–computer interfaces	Fully implantable, wireless brain–computer interface systems enabling high-bandwidth neural recording and stimulation	$363M+	Ultra-high channel-count neural implants combined with robotic surgical precision
NextMind	France / USA	Non-invasive BCIs	Wearable brain-sensing platform enabling intent-based control of digital interfaces via visual cortex signals	Acquired	Real-time decoding of visual attention and neural intent
Emotiv	USA	Neurofeedback and EEG	Portable EEG headsets for neuroscience research, wellness monitoring, and cognitive training	$10M+	Consumer-grade EEG systems integrated with cloud-based analytics
Kernel	USA	Brain activity mapping	Kernel Flow wearable for non-invasive measurement of cognitive states using optical neuroimaging	$100M+	Real-time functional brain monitoring based on time-domain fNIRS
Neurable	USA	BCI for AR/VR	EEG-integrated headphones enabling mental-state tracking and hands-free interaction in immersive environments	$13M+	Seamless integration of neural signals into consumer AR/VR platforms

mathematical optimization techniques, especially BO, have been increasingly leveraged to tune hyperparameters and control strategies in BCI systems, yielding significant gains in performance and adaptability.

One notable study demonstrated that BO, using Gaussian process surrogates and acquisition functions like expected improvement, achieved faster convergence and higher classification accuracy in deep-learning-based BCI models compared to grid and random search methods [49]-[50]. Another emerging approach integrates reinforcement learning (RL) principles, modeling the threshold adaptation of neurofeedback loops as a Markov Decision Process (MDP) and employing reward-maximizing policies to optimize user-specific control signals.

The BO is also an efficient method for reaching an optimal objective function, which employs statistical models and is primarily used when the objective function is unknown. After performing Bayesian optimization, the best sampling point is determined by the expected improvement function. To derive the Bayesian optimization relationship, an unknown objective function such as $f(x)$ is first defined as shown in (1).

$$\arg\max_{x\in\mathcal{X}} f(x) = x^* \tag{1}$$

The function $f(x)$ is also an unknown objective function and is not directly used in computations. Therefore, statistical models such as the Gaussian model are used for modeling, which is formulated as (2).

$$\mathcal{N}(\mu(x), \sigma^2(x)) \sim f(x) \tag{2}$$

In (2), the relationship, $\mu(x)$ represents the predicted mean and $\sigma(x)$ enotes the standard deviation. To generate a new point x, the optimal sampling strategy based on the expected improvement function is defined as Equation (3).

$$\max_{i=1,\ldots,n} f(x_i) = f(x^+) \tag{3}$$

In this relationship, $f(x^+)$ represents the maximum value of the objective function f(x). If $f(x^+)$ is determined according to the expected Improvement function at the point x, it corresponds to equation (4).

$$\mathbb{E}\left[\max\left(0, f(x) - f(x^+)\right)\right] = EI(x) \tag{4}$$

By applying the Gaussian relationship, the Expected Improvement function is then formulated, as expressed as (6).

$$\sigma(x)\phi(Z) + \left(\mu(x) - f(x^+)\right)\Phi(Z) = EI(x) \qquad (5)$$

In this relationship, represents the standard normal probability density function, and denotes the standard normal cumulative distribution function. Moreover, Z is derived from the expression $\frac{\mu(x)-f(x^+)}{\sigma(x)}$. Accordingly, the optimization of the expected improvement function is obtained as formulated in equation (7) [52],[54].

$$\arg\max_{x\in\mathcal{X}} EI(x) = x^* \qquad (6)$$

While RL aligns with the Bellman equation, one of the subfields of machine learning is reinforcement learning (RL). Reinforcement learning is essentially formed through interactions within an environment. This environment is modeled using MDP. The MDP is a mathematical modeling framework used for environments that are stochastic and time dependent and which is expresses as (8).

$$(S, A, P, R, \gamma) = \text{MDP} \qquad (7)$$

In (8), formulation,S is the set of states, A is the set of actions, and P is the state transition probability function is defined as $P(s' \mid s, a)$, which represents the probability of transitioning from state s to state s' under action a. The reward function R is defined as $R(s, a)$, indicating the reward received after executing action a in state s. The discount factor γ belongs to the interval $(0, 1)$ determining the importance of future rewards. Thus, in this case as well, the action-value function $Q^\pi(s, a)$ can also be used for modeling the reinforcement learning algorithm, which is formulated as (9).

$$\mathbb{E}_\pi\left[\sum_{k=0}^{\infty}\gamma^k R_{t+k+1} \,\middle|\, S_t = s,\ A_t = a\right] = Q^\pi(s, a) \qquad (9)$$

Thus, in this case as well, using the Bellman equation for the action-value function $Q^\pi(s, a)$, the relationship expressed in equation (10) is also obtained.

$$\mathbb{E}_\pi\left[R_{t+1} + \gamma Q^\pi(S_{t+1}, A_{t+1}) \mid S_t = s,\ A_t = a\right] = Q^\pi(s, a) \qquad (10)$$

In this case as well, the reinforcement learning algorithm is optimized as formulated in equation (11) [?] ,[?]

$$\mathbb{E}_\pi\left[R_{t+1} + \gamma \max_{a'} Q^*(S_{t+1}, a') \,\middle|\, S_t = s,\ A_t = a\right] = Q^*(s, a) \qquad (11)$$

The synergy of BO for hyperparameter tuning and RL for adaptive signal feedback creates a robust framework that can accelerate calibration, improve classification accuracy, and personalize neurofeedback protocols, paving the way for more responsive and efficient BCI systems. To formalize neuro-AI optimization, two key mathematical frameworks are introduced: Bayesian Optimization (BO) and Reinforcement Learning (RL). In BO, the optimal input x* is found by maximizing the expected improvement $E[EI(x)]$, where acquisition functions guide the sampling of high-potential configurations. Parameters include the search space xX, surrogate models (often Gaussian Processes), and objective evaluations. Meanwhile, RL employs the Bellman equation, where the Q-value function $Q(s, a)$ estimates the expected return for acting as in states, considering future discounted rewards RRR and policy . Here, denotes the discount factor, and the formulation enables adaptive feedback control in BCIs. Together, these models provide a dynamic optimization backbone for real-time calibration, signal adaptation, and user-specific performance enhancement in brain-computer interface systems [51] .

Despite rapid advancements, neurotechnology remains a frontier with unanswered questions and untapped potential. One of the most pressing areas for future research is hybrid systems that blend invasive and non-invasive BCIs to combine precision with usability. Research could explore ways to miniaturize components and improve signal fidelity in wireless systems, making these tools accessible for everyday cognitive support [55]. Another critical domain is the integration of real-time adaptive AI algorithms with BCIs, allowing devices to learn from user brain patterns and personalize outputs over time. There is also a need for deeper investigations into long-term safety and neural plasticity: What are the sustained effects of stimulation or decoding over years of use? How do such systems reshape cognitive architecture? Ethical and regulatory research must also evolve. As neurotechnology touches on identity, autonomy, and agency, interdisciplinary studies should assess the psychological impacts of thought-to-action translation, especially in contexts like military deployment or corporate productivity tools. Moreover, scholars should examine cross-cultural perceptions and disparities in access to neuroenhancement technologies. Without proactive policy development, these tools risk deepening existing global inequities. Finally, emerging research should focus on multimodal interfaces combining neural data with bio-signals (e.g., heart rate, skin conductance) to create comprehensive mental state monitoring tools, paving the way for holistic mental performance platforms [56].

6. Business sector applications: The commercial frontier of neurotechnology

6.1. Consumer neurotech and wearable markets

The rise of consumer-focused neurotechnology has opened new frontiers in wellness, productivity, and biofeedback. Companies, named Neurosity, Emotiv, and NextMind are introducing lightweight, user-friendly BCIs for meditation, focus enhancement, and gaming. These products capitalize on the rising demand for quantified self and mental performance tools. As algorithms improve in real-time brainwave interpretation, the potential for neurotech to become a daily personal companion grows exponentially [57].

6.2. Healthcare and neurotherapeutic devices

Neurotechnology is redefining the healthcare sector by offering non-pharmacological solutions for chronic conditions such as epilepsy, Parkinson's disease, and depression.

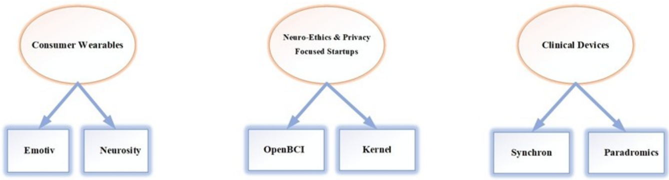

Figure 8: Commercial neurotechnology landscape.

Companies like Synchron and Paradromics are racing to bring implantable neuroprosthetics to market. Their business models prioritize clinical validation, regulatory navigation, and payer adoption strategies to ensure scalability in hospital systems and insurance networks [58]. A critical success factor is demonstrating cost-effectiveness and long-term patient outcomes.

6.3. Ethical branding and competitive differentiation

As neurotech enters sensitive cognitive territory, companies must embrace ethical branding, transparency about data use, user consent, and cognitive safety. Startups that lead with neuro-rights protections, like customizable privacy settings and opt-in brain data sharing, will gain consumer trust. Moreover, brands can differentiate through emotional impact by positioning their product as a tool for empowerment and well-being, not just enhancement. Early engagement with policymakers and ethical scholars is also becoming a strategic advantage [59].

The invasive BCI market is valued at approximately USD 160.44 billion in 2024, with a projected compound annual growth rate (CAGR) of 1.49% from 2025 to 2030. Based on recent studies, BCI demonstrates significant potential for treating various conditions, including depression, Parkinson's disease, limb amputation, epilepsy, spinal cord injuries, motor neuron disease/amyotrophic lateral sclerosis (ALS), stroke, multiple sclerosis, and cerebral palsy. The performance growth associated with each condition is illustrated in Figure 9. The overall estimated CAGR in the global market is 1.5%. The non-invasive BCI segment is projected to reach approximately USD 368.60 million globally by 2024, with an anticipated CAGR of 9.35% from 2025 to 2030. BCI applications in the global market are not limited to medical treatment and rehabilitation; they also extend to smart home control, healthcare, entertainment and gaming, communication, and control, as shown in Figure 10 [61].

BCI has had a significant impact during the COVID-19 pandemic and has also found applications in medical technologies, including assisting patients with neurological disorders such as Alzheimer's, Parkinson's, and Amyotrophic Lateral Sclerosis (ALS), as well as enabling remote patient monitoring systems. According to reports by the World Health Organization, the number of individuals affected by dementia is projected to reach 82 million by 2030 and 152 million by 2050. Figure 11 presents a global overview of the BCI market, illustrating that noninvasive BCIs are utilized across several continents and regions, including North America, Europe, Asia-Pacific, Latin America, the Middle East, and Africa. BCI applications include healthcare, functional restoration, and brain function rehabilitation. It is also employed in the treatment of conditions such as motor neuron disease/ALS, stroke, spinal cord injury, multiple sclerosis, cerebral palsy, and limb amputation. Ultimately, BCI is used in medicine, education, and research, and other areas (consumer, wellness, etc.), with more than 21 countries currently adopting the technology [60]. BCI in the global market was valued at approximately USD 125.21 million in 2018, with a projected annual growth rate (CAGR) of 12.43% through 2025. Figure 12 illustrates the trends in the global BCI market [61].

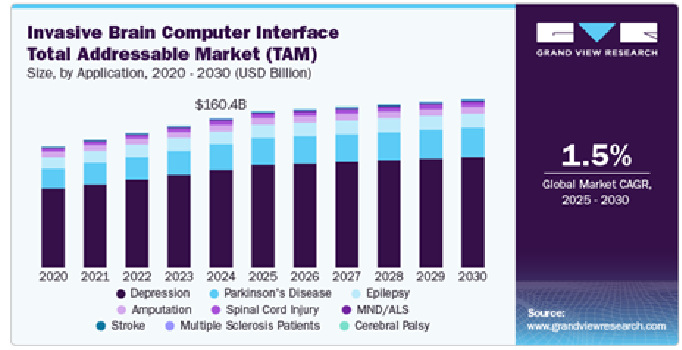

Figure 9: Invasive BCI performance in the global market by medical condition [60].

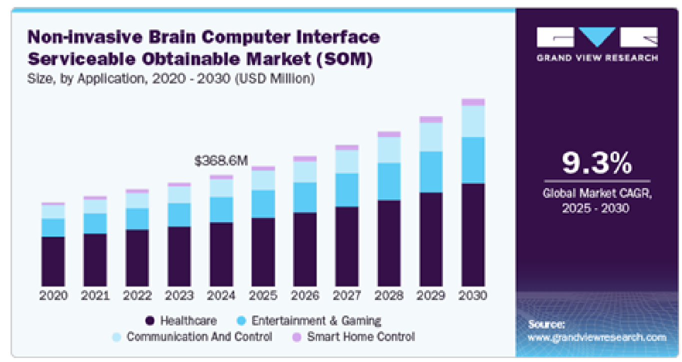

Figure 10: Non-invasive BCI performance in the global market for control and smart technologies [60].

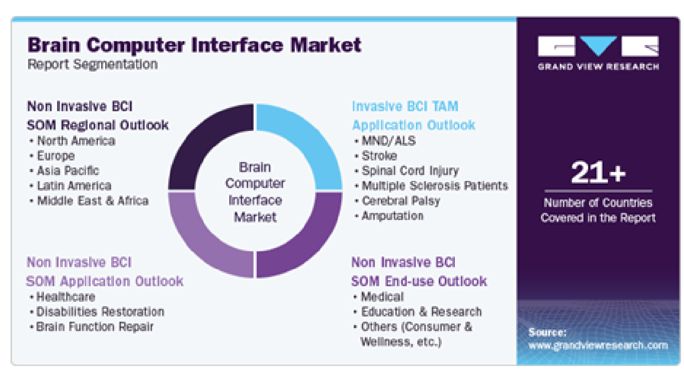

Figure 11: Global overview of the BCI market [60].

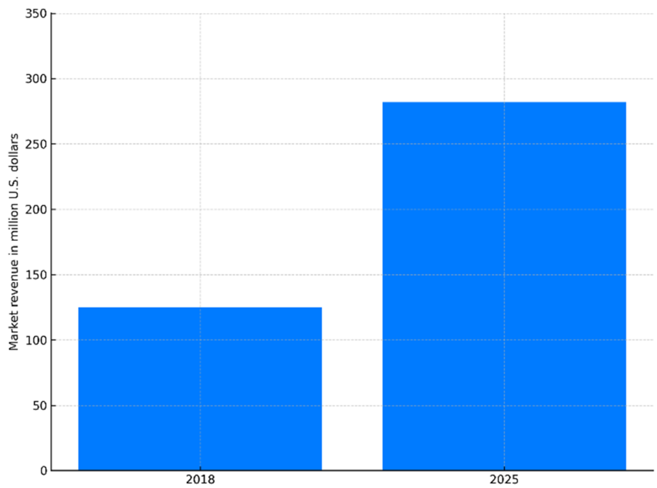

Figure 12: Global market trends of BCI.

7. Conclusion

This paper has explored the dual pathways through which human potential can be enhanced: internal cognitive self-regulation and external neurotechnological augmentation. While mind management strategies offer proven frameworks for improving focus, emotional regulation, and mental energy, brain-computer interfaces and neurostimulation devices directly mediate neural activity. Together, these approaches signal a new era in cognitive science, one where introspective and technological methods converge to expand the boundaries of performance, creativity, and human well-being. As the capabilities of neurotechnology grow from invasive BCIs and responsive neurostimulation to wearable AI-integrated devices, the ethical landscape grows more complex. Issues of autonomy, privacy, and the neuro-rights of individuals must be addressed with the same rigor as technological development. Mathematical models and algorithmic precision are increasingly used to optimize neural signal interpretation and treatment outcomes, demanding interdisciplinary scrutiny across neuroscience, data science, and bioethics. Future advancements must, therefore, balance efficacy with equity, accessibility, and long-term impact on mental sovereignty. The convergence of neurotechnology and cognitive psychology presents a clinical or commercial opportunity and a civilizational moment. Whether applied in healthcare, education, defense, or entrepreneurship,these tools must be guided by ethical foresight and societal consensus. As human cognition becomes increasingly modifiable, the challenge is not to innovate but to do so wisely. A truly enhanced future lies not only in smarter chips or sharper minds but also in an integrated vision that honors both the machine's precision and the mind's depth.

Declarations and Ethical Statements

Conflict of Interest: The authors declare that there is no conflict of interest.
Funding: This research received no external funding.
Availability of data and materials: Data used from secondary sources has been cited in the article.
Artificial Intelligence Ethical Statement: During the preparation of this work, the author(s) used ChatGPT to assist with grammatical corrections. After using this tool, the author(s) reviewed and edited the content as needed and take full responsibility for the content of the published article.
Publisher's note: The Journal and the Publisher remain neutral about jurisdictional claims in published maps and institutional affiliations.

References

[1] Malicse A. Cognitive optimization in the age of AI: enhancing human potential. Available from: https://philarchive.org/rec/MALCOI-2

[2] Ghimire MR, Subedi D. The effectiveness of mind management-based interventions in adolescent well-being, empowerment, and academic performance. Available from: https://elibrary.ku.edu.np/handle/20.500.14301/443

[3] Martinez W, Benerradi J, Midha S, Maior HA, Wilson ML. Understanding the ethical concerns for neurotechnology in the future of work. In: *Proceedings of the 1st Annual Meeting of the Symposium on Human–Computer Interaction for Work*. 2022 Jun 8; p. 1–19. Available from: https://doi.org/10.1145/3533406.3533423

[4] Bernal SL, Celdrán AH, Pérez GM, Barros MT, Balasubramaniam S. Security in brain–computer interfaces: state-of-the-art, opportunities, and future challenges. *ACM Computing Surveys*. 2021;54(1):1–35. Available from: https://doi.org/10.1145/3427376

[5] Ligthart S, Ienca M, Meynen G, Molnar-Gabor F, Andorno R, Bublitz C, Catley P, Claydon L, Douglas T, Farahany N, Fins JJ. Minding rights: mapping ethical and legal foundations of neurorights. *Cambridge Quarterly of Healthcare Ethics*. 2023;32(4):461–481. Available from: https://doi.org/10.1017/S0963180123000245

[6] Gordon EC, Seth AK. Ethical considerations for the use of brain–computer interfaces for cognitive enhancement. *PLoS Biology*. 2024;22(10):e3002899. Available from: https://doi.org/10.1371/journal.pbio.3002899

[7] Yuste R, Goering S, Arcas BA, Bi G, Carmena JM, Carter A, Fins JJ, Friesen P, Gallant J, Huggins JE, Illes J. Four ethical priorities for neurotechnologies and AI. *Nature*. 2017;551(7679):159–163. Available from: https://www.nature.com/articles/551159a

[8] Parhamfar M, Shojaei S, Hajarkesht A, Pinnarelli A, Soleimani A. Towards the applications of blockchain in distribution networks: a brief review. *Energy Systems Review*. 2025;8(2). Available from: http://dx.doi.org/10.25729/esr.2025.02.0002

[9] Parhamfar M, Eidiani M, Abtahi M. Distributed energy storage system: case study. In: *Distributed Energy Storage Systems for Digital Power Systems*. Elsevier; 2025. p. 395–422. Available from: https://doi.org/10.1016/B978-0-443-22013-5.00013-7

[10] Parhamfar M, Güven AF, Pinnarelli A, Vizza P, Soleimani A. Artificial intelligence in carbon trading: enhancing market efficiency and risk management. *Journal of Computing and Data Technology*. 2025;1(1):19–39. Available from: https://doi.org/10.71426/jcdt.v1.i1.pp19-39

[11] Parhamfar M, Adeli AM. Study of electrical grid components after installing a 10 MW photovoltaic power plant with large-scale batteries at peak load using DIgSILENT software. *American Journal of Electrical Power and Energy Systems*. 2022;11(5):97–107. Available from: https://doi.org/10.11648/j.epes.20221105.12

[12] Shih JJ, Krusienski DJ, Wolpaw JR. Brain–computer interface technology: current status and future prospects. *Mayo Clinic Proceedings*. 2012;87(3):268–279. Available from: https://doi.org/10.1016/j.mayocp.2011.12.008

[13] Gross JJ. Emotion regulation: current status and future prospects. *Psychological Inquiry*. 2015;26(1):1–26. Available from: https://doi.org/10.1080/1047840X.2014.940781

[14] Sirois F, Pychyl T. Procrastination and the priority of short-term mood regulation: consequences for future self. *Social and Personality Psychology Compass*. 2013;7(2):115–127. Available from: https://doi.org/10.1111/spc3.12011

[15] Smyth JM, Johnson JA, Auer BJ, Lehman E, Talamo G, Sciamanna CN. Online positive affect journaling for mental distress: a randomized controlled trial. *JMIR Mental Health*. 2018;5(4):e11290. Available from: https://doi.org/10.2196/11290

[16] Berkman ET. The neuroscience of goals and behavior change. *Consulting Psychology Journal: Practice and Research*. 2018;70(1):28–44. Available from: https://doi.org/10.1037/cpb0000094

[17] Burnette JL, Knouse LE, Billingsley J, Earl S, Pollack JM, Hoyt CL. Growth mindset intervention implementation strategies: a systematic review. *Social and Personality Psychology Compass*. 2023;17(2):e12723. Available from: https://doi.org/10.1111/spc3.12723

[18] Lozano AM, Lipsman N, Bergman H, Brown P, Chabardes S, Chang JW, Matthews K, McIntyre CC, Schlaepfer TE, Schulder M, Temel Y. Deep brain stimulation: current challenges and future directions. *Nature Reviews Neurology*. 2019;15(3):148–160. Available from: https://www.nature.com/articles/s41582-018-0128-2

[19] Laker V, Simmonds-Buckley M, Delgadillo J, Palmer L, Barkham M. Pragmatic randomized controlled trial of the Mind Management Skills for Life programme. *Journal of Mental Health*. 2023;32(4):752–760. Available from: https://doi.org/10.1080/09638237.2023.2182423

[20] FindLight. Evolution and future of brain–machine interface in 2024 [Online]. Available from: https://www.findlight.net/blog/evolution-and-future-of-brain-machine-interface-in-2024/

[21] Laydevant J, Wright LG, Wang T, McMahon PL. The hardware is the software. *Neuron*. 2024;112(2):180–183. Available from: https://doi.org/10.1016/j.neuron.2023.11.004

[22] Chan E. The FDA and the future of the brain–computer interface: Adapting FDA device law to the challenges of human–machine enhancement. *UIC John Marshall Journal of Information Technology & Privacy Law*. 2007;25(1):117–146. Available from: https://repository.law.uic.edu/cgi/viewcontent.cgi?article=1003&context=jitpl

[23] Neuroscience News. Neuralink, brain–computer interfaces and neuroethics. 2024. Available from: https://neurosciencenews.com/neuralink-bci-neuroethics-255555/

[24] Chen XL, Xiong YY, Xu GL, Liu XF. Deep brain stimulation. *Interventional Neurology*. 2013 Aug;1(3–4):200–212. Available from: https://doi.org/10.1159/000353121

[25] Price JB, Rusheen AE, Barath AS, Cabrera JM, Shin H, Chang SY, Kimble CJ, Bennet KE, Blaha CD, Lee KH, Oh Y. Clinical applications of neurochemical and electrophysiological measurements for closed-loop neurostimulation. *Neurosurgical Focus*. 2020 Jul;49(1):E6. Available from: https://doi.org/10.3171/2020.4.FOCUS20167

[26] Musk E. An integrated brain–machine interface platform with thousands of channels. *Journal of Medical Internet Research*. 2019 Oct;21(10):e16194. Available from: https://doi.org/10.2196/16194

[27] Vanneste S. Let's shape learning into lasting memories. *Neuroscience Insights*. 2024 Feb;19:26331055241227220. Available from: https://doi.org/10.1177/26331055241227220

[28] Lapenta OM, Rêgo GG, Boggio PS. Transcranial electrical stimulation for procedural learning and rehabilitation. *Neurobiology of Learning and Memory*. 2024 Sep;213:107958. Available from: https://doi.org/10.1016/j.nlm.2024.107958

[29] Toth AJ, Bruton AM, Campbell MJ. Neurostimulation: Exploring perceptual and cognitive enhancement. *Frontiers in Psychology*. 2025 Jun;16:1583115. Available from: https://doi.org/10.3389/fpsyg.2025.1583115

[30] Luu DK, Nguyen AT, Jiang M, Drealan MW, Xu J, Wu T, Tam WK, Zhao W, Lim BZ, Overstreet CK, Zhao Q. Artificial intelligence enables real-time and intuitive control of prostheses via nerve interface. *IEEE Transactions on Biomedical Engineering*. 2022 Oct;69(10):3051–3063. Available from: https://doi.org/10.1109/TBME.2022.3160618

[31] Neuroscience News. Neurotechnology and brain–computer interfaces. 2023. Available from: https://neurosciencenews.com/neurotech-bci-18953/

[32] Khrisna BM, Jhansi VC, Shama PS, Leelambika AB, Prakash C, Manikanta BV. Novel solution to improve mental health by integrating music and IoT with neural feedback. *Journal of Computational Information Systems*. 2019;15(3):234–239.

[33] Huh H, Shin H, Li H, Hirota K, Hoang C, Thangavel S, D'Alessandro M, Feltman KA, Sentis L, Lu N. A wireless forehead e-tattoo for mental workload estimation. *Device*. 2025 May. Available from: https://www.cell.com/device/fulltext/S2666-9986(25)00094-8

[34] Ahmed S, Momin M, Ren J, Lee H, AlMahmood B, Huang LP, Pandiyan A, Veeramuthu L, Kuo CC, Zhou T. Stick-and-play bioadhesive hairlike electrodes for chronic EEG recording on human skin. *npj Biomedical Innovations*. 2025 Mar;2(1):9. Available from: https://doi.org/10.1038/s44385-025-00009-x

[35] Vaghasiya JV, Mayorga-Martinez CC, Pumera M. Wearable sensors for telehealth based on emerging materials and nanoarchitectonics. *NPJ Flexible Electronics*. 2023 Jun;7(1):26. Available from: https://doi.org/10.1038/s41528-023-00261-4

[36] Sattler S, Jacobs E, Singh I, Whetham D, Bárd I, Moreno J, Galeazzi G, Allansdottir A. Neuroenhancements in the military: A mixed-method pilot study on attitudes of staff officers to ethics and rules. *Neuroethics*. 2022 Apr;15(1):11. Available from: https://doi.org/10.1007/s12152-022-09490-2

[37] Jasoren. Augmented reality in military applications. 2024. Available from: https://www.jasoren.com/augmented-reality-military/

[38] Oh J, Kim J. Military application study of BCI technology using brain waves in Republic of Korea Army. *Journal of Advances in Military Studies*. 2022 Apr;5(1):35–48. Available from: https://doi.org/10.37944/jams.v5i1.115

[39] Gielas AM. Soldier enhancement through brain–computer interfaces: The risks of changing the human condition. *The RUSI Journal*. 2025 Jan;170(1):32–47. Available from: https://doi.org/10.1080/03071847.2025.2449894

[40] Wu J, Wang Z, Xu T, Sun C. Driving mode selection through SSVEP-based BCI and energy consumption analysis. *Sensors*. 2022 Jul;22(15):5631. Available from: https://doi.org/10.3390/s22155631

[41] Yoon Y, Cho IJ. A review of human augmentation and individual combat capability: Focusing on MEMS-based neurotechnology. *Micro and Nano Systems Letters*. 2024 Sep;12(1):17. Available from: https://doi.org/10.1186/s40486-024-00205-1

[42] Bonci A, Fiori S, Higashi H, Tanaka T, Verdini F. An introductory tutorial on brain–computer interfaces and their applications. *Electronics*. 2021 Feb;10(5):560. Available from: https://doi.org/10.3390/electronics10050560

[43] Munyon CN. Neuroethics of non-primary brain computer interface: Focus on potential military applications. *Frontiers in Neuroscience*. 2018 Oct;12:696. Available from: https://doi.org/10.3389/fnins.2018.00696

[44] Latheef S. Brain-to-brain interfaces in future military operations: Blurring the boundaries of individual responsibility. *Monash Bioethics Review*. 2023 Jun;41(1):49–66. Available from: https://doi.org/10.1007/s40592-022-00171-7

[45] Parhamfar M. Navigating mid-career precariousness: Employment challenges for Iran's workforce (ages 34–44). 2024. Available

from: https://doi.org/10.13140/RG.2.2.17594.30403

[46] Parhamfar M. The AI advantage: Powering your startup's future in Iran. 2024. Available from: https://doi.org/10.13140/RG.2.2.10151.87201

[47] Zhang Z, Chen Y, Zhao X, Fan W, Peng D, Li T, Zhao L, Fu Y. A review of ethical considerations for the medical applications of brain–computer interfaces. *Cognitive Neurodynamics*. 2024 Dec;18(6):3603–3614. Available from: https://doi.org/10.1007/s11571-024-10144-7

[48] Wilkins RB, Coffin T, Pham M, Klein E, Marathe M. Bridging ethical considerations and regulatory oversight in implantable BCI research. *Frontiers in Human Neuroscience*. 2025 Jul;19:1633627. Available from: https://doi.org/10.3389/fnhum.2025.1633627

[49] Watkins CJ, Dayan P. Q-learning. *Machine Learning*. 1992 May;8(3):279–292. Available from: https://doi.org/10.1007/BF00992698

[50] Sarikaya MA, Ince G. Improved BCI calibration in multimodal emotion recognition using heterogeneous adversarial transfer learning. *PeerJ Computer Science*. 2025 Jan;11:e2649. Available from: https://doi.org/10.7717/peerj-cs.2649

[51] Xie T, Jiang N. Q* approximation schemes for batch reinforcement learning: A theoretical comparison. In: *Proceedings of the Conference on Uncertainty in Artificial Intelligence*. 2020 Aug;PMLR; p. 550–559. Available from: https://proceedings.mlr.press/v124/xie20a.html

[52] Shahriari B, Swersky K, Wang Z, Adams RP, De Freitas N. Taking the human out of the loop: A review of Bayesian optimization. *Proceedings of the IEEE*. 2016 Jan;104(1):148–175. Available from: https://doi.org/10.1109/JPROC.2015.2494218

[53] Brochu E, Cora VM, De Freitas N. A tutorial on Bayesian optimization of expensive cost functions. *arXiv preprint*. 2010 Dec. Available from: https://doi.org/10.48550/arXiv.1012.2599

[54] Hu S, Wang H, Dai Z, Low BK, Ng SH. Adjusted expected improvement for cumulative regret minimization in noisy Bayesian optimization. *Journal of Machine Learning Research*. 2025;26(46):1–33. Available from: https://www.jmlr.org/papers/v26/22-0523.html

[55] Nijboer F, Clausen J, Allison BZ, Haselager P. The Asilomar survey: Stakeholders' opinions on ethical issues related to brain–computer interfacing. *Neuroethics*. 2013 Dec;6(3):541–578. Available from: https://doi.org/10.1007/s12152-011-9132-6

[56] Sirbu R, Morley J, Schroder T, Pothukuchi RP, Ugur M, Bhattacharjee A, Floridi L. Regulating next-generation implantable brain–computer interfaces. *arXiv preprint*. 2025 Jun. Available from: https://doi.org/10.48550/arXiv.2506.12540

[57] Tarara P, Przybył I, Schöning J, Gunia A. Motor imagery-based brain–computer interfaces using Emotiv EPOC X. *Frontiers in Neuroinformatics*. 2025 Aug;19:1625279. Available from: https://doi.org/10.3389/fninf.2025.1625279

[58] Dohle E, Swanson E, Jovanovic L, Yusuf S, Thompson L, Horsfall HL, Muirhead W, Bashford L, Brannigan J. Toward the clinical translation of implantable brain–computer interfaces for motor impairment. *Advanced Science*. 2025 Aug;12(32):e01912. Available from: https://doi.org/10.1002/advs.202501912

[59] Szoszkiewicz Ł, Yuste R. Mental privacy: Navigating risks, rights and regulation. *EMBO Reports*. 2025 Jun. Available from: https://doi.org/10.1038/s44319-025-00505-6

[60] Grand View Research. Brain–computer interfaces market analysis. 2025. Available from: https://www.grandviewresearch.com/industry-analysis/brain-computer-interfaces-market

[61] Statista. Brain–computer interfaces statistics and market data. 2025. Available from: https://www.statista.com/search/?q=Brain+Computer+Interfaces