Human Enhancement Technologies and the Possible Dual Use in Cognitive Warfare

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ABSTRACT

Emerging scientific frontiers in genome editing and brain - computer interfaces (BCIs) promise unparalleled advancements in human health and cognitive capacities. Genome editing, with its potential to modify genetic sequences, might one day enhance traits including cognitive function. Concurrently, BCIs, enabling direct brain-device interplay, present prospects in cognitive enhancement such as amplified memory or learning rates. Yet, as the horizons of these technologies expand, so too do the ethical quagmires, chiefly, the dual-use dilemma in cognitive warfare. There is potential for these technologies to uplift society, offering enhanced cognitive abilities and a new echelon of human capability. Conversely, their weaponization in cognitive warfare could be two-fold: creation of genetically superior individuals or the intentional cognitive degradation of adversaries. Such malevolent uses might range from deploying genome-edited viruses targeting specific cognitive traits to using BCIs for information theft or remote control. While the paper delves deep into these dimensions, it underscores that societal and technological safeguards could be instrumental in curbing misuse in cognitive warfare. As these technologies burgeon, it becomes imperative to balance their promise with robust ethical considerations, ensuring their deployment for societal benefit rather than detriment.

1.0 INTRODUCTION

Cognitive warfare, which aims to exploit cognition facets to disrupt, undermine, influence, or modify human and technological decisions, has become an increasingly significant area of focus in modern military strategy [1]. NATO Allied Command Transformation (ACT) defines cognitive warfare as activities conducted in synchronization with other instruments of power to affect attitudes and behavior by influencing, protecting, or disrupting individual and group cognition to gain advantage over an adversary [2]. The ability to manipulate or even control the cognitive capabilities of an adversary has the potential to drastically reshape the landscape of conflict, shifting the focus from the physical to the psychological battlefield [3], [4]. Technological advances have further amplified the potential impact and implications of cognitive warfare, creating new opportunities for cognitive enhancement as well as new threats to cognitive security. Innovations such as brain implants and genome editing, although currently at low Technology Readiness Levels (TRL), hold substantial promise for future applications in cognitive warfare. These technologies have the potential to not only enhance cognitive performance but also introduce vulnerabilities that could be exploited by adversaries [5], [6]. In this context, the potential misuse of human enhancement technologies for cognitive warfare warrants serious attention and consideration. For example, genome editing could be used to introduce harmful cognitive traits into a population [7], while brain implants could be manipulated to disrupt an individual's cognitive processes. Conversely, these technologies could also be used to enhance cognitive capabilities, enhancing decision-making, increasing resilience, and fostering innovation within a military context and the broader society [8], [9]. Moreover, the role of cognitive warfare extends beyond the battlefield, with strategic implications for geopolitical competition and national security. Several countries, including those of the North Atlantic Treaty Organization (NATO) and the People's Republic of China (PRC), are increasingly interested in high-tech industries and advancements in fields such as genetics, neuroscience, and artificial intelligence (AI) [10], [11]. These technologies have the potential to create strategic advantages, reshaping the balance of power on the global stage [12]. In addition to these strategic considerations, there are significant ethical, societal, and safety considerations that must be addressed. The manipulation of cognitive processes raises profound questions about autonomy, consent, and the potential for misuse. As such, robust regulation, oversight, and public dialogue are essential to ensure these technologies are developed and used responsibly. As we navigate this new frontier in cognitive warfare, we must approach these developments with a nuanced understanding of their potential implications, both beneficial and detrimental. By exploring the opportunities and risks presented by brain implants and genome editing, this paper aims to contribute to this understanding and to stimulate discussions on how to navigate this evolving landscape responsibly and ethically.

2.0 HUMAN ENHANCEMENT TECHNOLOGIES

Human enhancement refers to any attempt to temporarily or permanently overcome the current limitations of the human body through natural or artificial means. The term is sometimes applied broadly to include cognitive enhancement (improving intellectual capacity), physical improvement (such as resistance to disease or improving physical capacity), genetic enhancement, life extension, mood improvement, and more. This chapter provides an introduction to the background and current state of the two selected technologies, genome editing and brain-computer interfaces (BCI).

2.1 Genome Editing for Cognitive Enhancement

In this section, we will explore the development of genome editing technologies and the complex relationship between genetics and cognitive abilities. Cognitive functions, such as perception, attention, understanding, memory, reasoning, and control of motor responses, form the bedrock of our ability to process and organize information. In the realm of cognitive enhancement, genome editing technologies may be utilized to enhance traits, not only to bolster military performance, but also to engender a more intellectually adept populace, potentially yielding an economic advantage [8]. The potential power of these technologies comes with considerable challenges, including the risks of unintended gene modifications and disruptions of vital genes. Yet, the field is advancing rapidly, bringing us closer to the capability of precisely altering the genetic and molecular foundation of cognitive abilities.

2.1.1 Genome Editing Technologies STO Third Level Heading

The two primary approaches of genome editing for cognitive enhancement are germline and somatic editing [7]. Germline editing involves altering the genes in the egg or sperm cells, causing the changes to be heritable and affecting all cells in the organism. This method, however, raises significant ethical issues as any potential negative effects would also be passed on to future generations. Currently, germline editing is largely prohibited in humans due to these ethical concerns [7]. On the other hand, somatic genome editing, involves modifying genes in specific body cells, typically in adulthood, with effects not inherited by offspring It is considered more ethically acceptable and is the primary focus of current research and development. [7]. However, in late 2018, the scientific community was rocked by the announcement of the birth of the world's first genetically edited human babies. Dr. He Jiankui, a Chinese biophysics researcher, claimed that he had successfully edited the genes of twin embryos to make them resistant to HIV. He utilized the CRISPR-Cas9 genome-editing technology, which allows for precise modifications to be made to the DNA of living organisms [7].

Ensuring precise and effective delivery of genetic material is an essential aspect of genome editing technologies. In the early stages of genome editing, viruses were often used as vectors due to their natural ability to infect cells and integrate their genetic material. Retroviruses, including lentiviruses, were commonly used in this capacity due to their ability to integrate into the host genome, providing long-term expression of the introduced gene [13]. However, this approach has several limitations, including the potential for insertional mutagenesis if the viral vector inserts in an essential part of the genome [13]. Non-viral methods like CRISPR, offer more control and are less likely to trigger an immune response. CRISPR-Gold, a non-viral delivery vehicle for the CRISPR-Cas9 ribonucleoprotein, has successfully modified genes in the brains of adult mice, highlighting its potential for human application [14]. In general, CRISPR-based methods have rapidly gained favor over older techniques based on Zinc Finger Nucleases (ZFNs) or Transcription Activator-Like Effector Nucleases (TALENs) in clinical studies [7]. One of the key technical challenges to overcome in the use of these technologies, particularly in the context of cognitive enhancement, is the blood-brain barrier. However, recent advances in the use of adeno-associated viral vectors (AAV) suggest that this challenge might be surmountable. AAVs are a promising option for the delivery of CRISPR due to their ability to cross the blood-brain barrier, and their use reduces the likelihood of off-target effects [7]. They have a high capacity for foreign DNA and do not integrate their DNA into the host cell's genome, reducing the risk of insertional mutagenesis. However, they can induce strong immune responses, which might limit their use [7]. Gene drives, which ensure that a particular trait is preferentially inherited, could also potentially be used in the context of cognitive enhancement. However, this technology is still in its early stages, and its use in humans is currently subject to strict regulation due to ethical and ecological concerns. Its use would likely be limited to altering populations of non-human organisms, such as mosquitoes to combat malaria [7].

2.1.2 Genetics and Cognitive Abilities

The key obstacle to the successful application of genome editing for cognitive enhancement is the significant knowledge gap in understanding the genetic and molecular mechanisms that underpin human cognition [7]. The complexity of cognitive traits can be attributed to their polygenic nature, with hundreds, if not thousands, of genes contributing to each trait [15]. Each gene often has a small effect and interacts with others in a complex, and often nonlinear, manner. This makes it extremely challenging to isolate specific genes or genetic variants that have a substantial and anticipated influence on cognitive abilities. The lack of specific knowledge on how to manipulate these genes, and the potentially unpredictable outcomes of such manipulations, present significant barriers to the use of gene therapy for cognitive enhancement [15]. While our understanding of the human genome has greatly advanced in recent years, especially with the completion of the Human Genome Project and the advent of Genome-Wide Association Studies (GWAS), the intricate genetic basis of cognitive abilities remains largely elusive [15]. Nevertheless, recent advances, larger sample sizes, and more sophisticated analytic tools have accelerated the process [15]. Studies have identified 70 independent genomic loci associated with general cognitive ability, implicating about 350 genes in cognitive function [16]. In addition, AI and machine learning technologies are anticipated to play a significant role in speeding up the mapping of gene functions and their interactions. This field of study, known as functional genomics, has already benefited greatly from AI applications [17]. AI enables the analysis and interpretation of extensive genomic sequencing data, identifying intricate patterns and correlations that would be difficult or impractical for humans to discern manually. For example, AI can identify the roles of specific genes by recognizing patterns in their behavior under different conditions or in different disease states [17]. It can also predict how genes interact within complex biological systems [17], and subsequently pave the way for better-targeted genome editing technologies.

2.1 Brain-Computer Interfaces (BCIs)

Brain-computer interfaces (BCIs) represent a groundbreaking category of human enhancement technology that enable direct communication between the brain and external devices. This technology can be used for a variety of purposes, ranging from helping individuals with paralysis to control prosthetic limbs, to potentially enhancing cognitive abilities by connecting the brain directly to computers, or to communicating without a word from brain to brain [9]. The military has demonstrated significant interest in BCIs, especially for evaluating cognitive performance. The Army Research Laboratory (ARL) and the Air Force have pioneering innovative projects such as the development of helmets that incorporate EEG sensors to monitor brain activity, potentially enhancing the performance of pilots [9]. In the sections that follow, we will offer a brief historical overview of BCIs, and then delve into current innovations, applications, and future prospects particularly relevant to the military sector.

2.2.1 Background

The exploration and development of Brain-Computer Interfaces (BCIs), also known as Brain-Machine Interfaces (BCIs), has been in progress for close to a century. The concept was first introduced in the scientific lexicon by Jacques Vidal in 1973, but the roots of BCI research can be traced back to the pioneering work of John Cunningham Lilly in the 1950s [18]. BCIs fall under two distinct categories: non-invasive and invasive technologies, with the latter requiring surgical procedures for implementation [9]. Critical to the ongoing journey of BCIs is the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) initiative by the National Institutes of Health (NIH). The initiative has played a transformative role in propelling research forward by allocating significant funding to improve our understanding of the human brain and to facilitate the shift from neuroscience to neurotechnology [9]. Since the genesis of basic BCIs in the1970s, the field has seen remarkable advancements that have substantially improved their performance.

2.2.2 Technological developments and Applications

The current state of Brain-Machine Interface (BCI) technology is characterized by remarkable advancements in both technology and application, with enterprises like Neuralink, co-founded by Elon Musk, making significant strides. Neuralink employs ultra-thin threads surgically implanted into the brain to interpret neural activity, minimizing tissue damage in comparison to traditional methods [19]. After thorough animal testing, Neuralink has embarked on FDA-approved human clinical trials, highlighting a significant milestone in the field. However, BCI technology isn't exclusive to Neuralink, with companies such as Precision and Synchron also contributing significantly. Synchron's Stentrode system, for example, allows those with severe paralysis to control tech devices with their thoughts and has launched an FDA-authorized study [20]. Other crucial advancements include the production of thin, flexible electrode arrays reducing tissue damage and inflammation, and improvements in machine learning and signal processing algorithms, speeding up and enhancing the accuracy of BCI-controlled devices [9]). Research at Wake Forest Baptist Medical Center and the University of Southern California backs this vision, with promising results in memory improvement through surgically implanted electrodes [21]. Applications of BCI have been transformative across several sectors, particularly healthcare. At Stanford University, BCIs have been used to enable paraplegic patients to control computer interfaces using their thoughts [22]. Further, the integration of BCI-powered prosthetics has revolutionized healthcare, restoring the ability to walk in monkeys and rats by reestablishing the connection between the motor cortex and the spinal cord [23]. Even brain-to-brain communication might become a reality, as demonstrated by a pilot study at the University of Washington, which developed a noninvasive system that interprets basic brain signals and transmits them over the internet [24]. The integration of AI with BCIs is a fascinating frontier, with Elon Musk predicting that this high-bandwidth interface to the brain could result in a symbiosis between human and machine intelligence [9].

In summary, BCIs, with their revolutionary potential especially in healthcare, are rapidly evolving thanks to advances in electrode design. While still in the early stages, they offer vast applications, from device mind control to improved memory and brain-to-brain communication. As this field progresses, it is vital to address ethical, societal, and security considerations. With careful innovation and consideration, BCIs hold the promise of deeply transforming our lives. As we press forward, ethical considerations, societal implications, and potential security issues should be at the forefront of our discussions and research.

3.0 HUMAN ENHANCEMENT TECHNOLOGIES IN COGNITIVE WARFARE: OPPORTUNITIES & BARRIERS

Cognitive warfare aims to exploit cognition facets to disrupt, undermine, influence, or modify human and technological decisions. NATO Allied Command Transformation (ACT) defines cognitive warfare as activities conducted in synchronization with other instruments of power to affect attitudes and behavior by influencing, protecting, or disrupting individual and group cognition to gain advantage over an adversary [2]. Given that cognitive enhancement technologies can potentially enhance decision-making capabilities, perception, memory, and overall cognitive functioning they could also be a key component of cognitive warfare. In this context, cognitive enhancement could be used not only in the struggle for cognitive superiority [25] but also as a means of defense against cognitive warfare tactics. In this chapter, we will explore potential ways human enhancement technologies, specifically genome editing and brain-machine interfaces (BCIs), could be utilized in cognitive warfare and the associated technical and societal barriers.

3.1 Genome Editing in Cognitive Warfare

Genome editing technologies like CRISPR might be used to enhance cognitive abilities in soldiers or intelligence operatives, in addition to the general population [7]. This could involve modifying genes associated with memory, attention, reaction time, resilience to stress, and even the need for sleep, all of which could provide a significant advantage in military or intelligence contexts. A population with enhanced cognition might be more resilient to disinformation campaigns or influence operations, as their improved critical thinking abilities would enable them to better evaluate and challenge the information they receive. However, the application of genome editing in cognitive warfare could also have a darker side. For example, an adversary might potentially develop biological weapons that specifically target cognitive functions, causing confusion, fear, or incapacitation.

3.1.1 Cognitive Enhancement of Military Personnel

In the theatre of war, human abilities are intrinsically constrained. However, military forces could potentially surmount these inherent limitations through the application of genome editing technologies, thereby enhancing the soldier beyond their natural capacity. Nation-states might consider genetically augmenting their militaries to amplify both the cognitive and physical capabilities of their combatants [7]. In 2019, the Department of Defense's Biotechnologies for Health and Human Performance Council enumerated nine potential enhancements that could significantly boost a soldier's battlefield performance. These were listed in order of likelihood of successful modification: 1) situational awareness, 2) strength and speed, 3) imaging and sight, 4) communication, 5) endurance, 6) virtual control, 7) attention and memory, 8) learning, and 9) olfaction [26].

It should be noted that some of these enhancements might be achieved through technologies other than genome editing. Where viable alternatives exist, it is arguably less likely that a nation would channel significant investment into genome editing for these particular traits [7]. Ethics and morality are at the forefront of considerations surrounding genome editing and the enhancement of soldiers. In many instances, these elements might be the pivotal factors influencing whether a state opts to embrace and apply such technology [27]. The intrusive nature of genome editing, which significantly impacts the lives of individual soldiers, transgresses societal norms. Striking a balance between the needs and welfare of individual soldiers and the military advantages offered by these technologies presents a complex task [28]. As a guiding principle, enhancements for soldiers should ideally be temporary. This means that any physical modifications like implants or robotic additions should be removable, and all biological or pharmaceutical changes should be reversible. However, reversibility remains a difficult proposition when it comes to genome editing. Even though theoretically it might be possible to reverse an introduced genomic change, the process could be doubly complicated and risky. Predicting and countering the long-term effects can be immensely challenging, and this might render a genomic alteration virtually irreversible, a consideration of utmost importance when deliberating the application of such technology. This is a subject of significant research interest, exemplified by a DARPA-sponsored 'safe genes' project working on developing ways to reverse alterations in genetically modified soldiers [29]. While the prospect of genome editing for enhancing traits like intelligence and immunity in the general population holds potential for long-term national advantage, its relevance to cognitive warfare should be cautiously evaluated. The use of genome editing technologies could theoretically support cognitive superiority or resilience against influencing operations [7]. However, the enhancement of a population's traits is not just a matter of scientific feasibility but also poses substantial ethical and societal challenges. Such large-scale genetic modifications could blur the distinction between medical treatment and enhancement, raising key issues about equity, consent, and societal acceptance. Decisions on beneficial traits for enhancement and access to such technologies may exacerbate societal inequalities, leading to a divide between genetically enhanced individuals and those who are not. Furthermore, the lack of consent from future generations affected by these enhancements and the considerable public apprehension about genetic manipulation underline the profound ethical implications of this approach. This underscores the need for a comprehensive and cautious approach in the realm of cognitive warfare when considering the potential, relative merits, and potential dangers of these enhancement technologies. It is essential to weigh these elements carefully to ensure that the pursuit of strategic advantages does not compromise fundamental ethical principles or inadvertently introduce far-reaching and potentially harmful effects on soldiers and future generations.

3.1.2 Dual Use of Gene Therapy

In gene therapy, modified viruses are used as vectors to deliver therapeutic genes to patients' cells. This same strategy could, in theory, be manipulated for malevolent purposes in cognitive warfare. Instead of therapeutic genes, harmful sequences—such as those causing gene deterioration or inducing negative cognitive effects—could be introduced. This could be genetic predispositions to cognitive impairments, mental health disorders, or susceptibility to the influence of cognitive warfare tactics. The choice of virus would indeed be a crucial consideration. The ideal choice would be a virus that is highly infectious, has a natural tropism (affinity) for the nervous system, and can cross the blood-brain barrier. Influenza viruses have high infection rates but primarily infect respiratory cells, not neurons. Other viruses like rabies or certain types of herpesviruses have a natural tropism for the nervous system and might be more suitable for this purpose. However, making such a weapon would require significant technical expertise and resources. As mentioned before, it would also require an in-depth understanding of the genetic and molecular basis of cognition that we currently do not have [15]. Moreover, the weapon's use would pose significant risks, as it could easily spread beyond the intended target population and cause a global pandemic. Even if it were technically feasible, such a strategy would be considered highly unethical and is prohibited by international law. The Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction (BTWC), for example, bans the development, production, and acquisition of biological and toxin weapons. However, the very possibility of such misuse underscores the importance of strong biosecurity measures and rigorous oversight of research involving genome editing and other potentially dual-use technologies (i.e., technologies that have both civilian and military applications). It is also worth noting that many of the negative consequences of this type of warfare might be achieved more simply and reliably through other means, such as traditional psychological operations or cyber warfare. Given the complexity and unpredictability of biological systems, biological warfare, especially at the cognitive level, is a risky and uncertain endeavor.

3.1.3 Modifying the Gut Microbiome

The gut-brain axis, a bidirectional communication channel between gut microbiota and the brain, has a significant impact on various aspects of brain function and behavior [30]. Altering the gut microbiome could influence cognition, mood, and behavior, making it a potential target in cognitive warfare. Researchers have already demonstrated the potential of using CRISPR-Cas9 systems to manipulate the gut microbiome in mammals. In a breakthrough study in November 2022, scientists were able to delete genes from Escherichia coli that were resident in the gut microbiome of mice, showing the potential to modify the DNA of microbes within the gut [31]. However, significant knowledge barriers need to be overcome to reliably employ such strategies. The gut microbiome is an extremely complex and dynamic system, with its composition varying substantially from individual to individual and across different populations. Thus, developing a comprehensive understanding of the microbiome and its influence on cognition remains a formidable challenge [7]. Moreover, there is the critical issue of delivery and targeting. If CRISPR were to be used to manipulate the gut microbiome at the population level, it would need to be delivered in a way that ensures it reaches the target microbes while avoiding off-target effects on other beneficial microbes [7]. One potential method could involve using a highly infectious but non-detrimental virus such as the norovirus to carry the CRISPR system. Yet, this approach raises several ethical and safety concerns. It would require a fine balance to avoid causing harm to human hosts or unintentionally creating more virulent pathogens.

3.1.4 Pathogen Modification and Gene Drives

In some cases, using virulent microorganisms can be a strategy in itself to affect cognitive functions. For example, the coronavirus SARS-CoV-2 has been associated with neurological effects in some patients. By applying genetic engineering techniques to modify these organisms, it could be possible to increase their potency or specifically enhance their cognitive-impacting traits making them an effective weapon in cognitive warfare. There are several challenges that actors will have to overcome to make pathogens more dangerous using genome editing [7]. There are properties that are inherent to viruses and bacteria that make them difficult to modify; gaps in our knowledge of the genetic determinants that underlie phenotypes; difficulties in transferring knowledge learned in one microbe to another microbe; and challenges acquiring agents that pose a severe threat to humans, animals, and plants because the transfer of such agents is controlled [7]. The genomes of viruses are smaller and have a restricted organization making it even more difficult to modify those compared with bacteria. Hence there is a considerable risk of reducing the fitness of the virus by modifications of a trait [7]. Additionally, actors who want to apply CRISPR to modify agents of concern such as SARSCOV 2 will have barriers in acquiring the agent since there are governmental instruments that oversees the possession, use and transfer of agents that are severe threats to humans, animals and plants [7]. Gene drives involve genetically engineering a species in a way that causes a specific trait to be disproportionately inherited by future generations. In theory, an adversary could use a gene drive to introduce detrimental cognitive traits into a population over time. The administration of a gene drive would likely involve the release of genetically modified organisms into the environment, which would then mate with the native population, spreading the harmful trait [7]. A vector species would need to be chosen that can mate quickly and prolifically and has extensive contact with the targeted human population. This approach would have a delayed but potentially widespread and persistent effect. Even if we knew precisely which genes to target to modify specific cognitive traits, achieving a meaningful impact on cognition through gene drives would be incredibly challenging. The adversary would need a comprehensive understanding of how specific genes interact with each other and the environment to influence cognition, which is currently beyond our scientific understanding [7]. Assuming this could be accomplished, the ethical implications are vast and profound.

3.2 Military Implications of Brain-Computer Interfaces (BCIs)

Brain-computer interfaces (BCIs) can provide an enhanced interface between the brain and the external environment, potentially augmenting cognitive capacities and enabling new forms of communication. In a military context, this could improve decision-making, increase situational awareness, facilitate faster communication, and even provide control over unmanned systems, such as drones, directly from the soldier's brain [9]. BCIs could also be used to enhance cognitive capabilities in the general population. For example, they might be used to improve learning capabilities or enable new forms of communication. This could foster innovation, increase productivity, and generally enhance societal resilience. Conversely, BCIs could be weaponized to disrupt the cognitive processes of adversaries. They could potentially deliver disruptive neural signals that interfere with decision-making or perceptions. The theoretical capacity for BCIs to remotely monitor cognitive workload, as well as the long-distance standoff assessments, would provide a substantial advantage in the theater of cognitive warfare. The integration of BCIs with the Internet of Things (IoT) also poses intriguing possibilities. The Department of Defense (DoD) already recognizes the potential of IoT for improved readiness, providing real-time status monitoring of material and weapons systems [9]. The combination of BCIs and IoT would enable warfighters to access sensors and data, enhancing their capabilities significantly. The integration of Brain-Computer Interfaces (BCIs) with the Internet of Things (IoT) also potentially presents a cybersecurity risk. This is because any device or system that is connected to the internet, including BCIs and IoT devices, is susceptible to hacking and cyber-attacks. In the context of cognitive warfare, an adversary could potentially exploit these vulnerabilities to compromise the system. For example, they might try to gain unauthorized access to the information being transmitted between the brain and the device, manipulate the data being sent to or from the BCI, or disrupt the operation of the BCI altogether. This could have serious implications, particularly in a military context where BCIs might be used to control unmanned systems or monitor the cognitive workload of soldiers. Nevertheless, several technological barriers hinder the practical application of BCIs. A significant challenge in BCI development lies in balancing the trade-off between the high-fidelity signals of invasive systems and the ease of use of noninvasive systems. Invasive systems carry risks associated with any surgery, such as hemorrhaging, infection, or brain damage, as well as potential complications from electrodes such as infections and degradation [9]. Current BCI implants are also prone to corrosion, limiting their useful lifespan to about two to five years. Additionally, the hardware necessary for BCIs, including amplifiers, cables, and sensors is currently too bulky for practical use outside a lab. Decoding the data gathered from neurons is another formidable challenge, often requiring machine learning and frequent recalibration due to changes in the position of neurons relative to electrodes, as well as natural shifts in firing patterns. As the marketplace drives technology, proactive policies will be crucial in shaping the trajectory of BCIs and managing potential risks and misuse. Companies such as Kernel, Neuralink, Paradromics, and Facebook are already actively pursuing BCI capabilities, pushing the envelope of what is possible. Societal barriers, particularly ethical issues, also pose significant challenges. The use of BCIs for cognitive enhancement raises questions about privacy and autonomy, potential societal impacts such as increased inequality, and concerns about the long-term effects on mental health. These ethical considerations underline the necessity for careful regulation and ongoing public dialogue to ensure the responsible development and deployment of this powerful technology.

3.2.1 BCIs and Cognitive Enhancement

Rapid advancements in military technology and an intensifying focus on strategic competition imply that future soldiers may face complex operational environments. Cognitive enhancement, through the application of technologies like Brain-Machine Interfaces (BCIs) and Artificial Intelligence (AI), can play a significant role in improving soldiers' performance in these situations [9]. In a future battlefield shaped by the Internet of Things (IoT), cognitive enhancement technologies can assist soldiers in managing the overwhelming influx of information from soldier-worn sensors, unmanned aircraft, and other smart devices. BCI could support the rapid transfer and utilization of large amounts of data, aiding soldiers in swift decision-making and effective engagement with AI systems [9]. As AI continues to integrate into military operations, the speed of warfare is expected to accelerate. In response, cognitive enhancement could help quicken decision-making cycles, reducing cognitive load and enabling soldiers to make informed decisions within a compressed timeframe. For example, in a future BCI test AI could transfer initial data analysis from a drone directly to the relevant centers of an operator's brain [9]. Cognitive enhancement also has potential applications for managing the increasing number of autonomous and semi-autonomous systems on the battlefield. For instance, BCIs could offer hands-free control of vehicles, drones, or even drone swarms, freeing operators to focus on other tasks [9]. Moreover, cognitive enhancement could offer significant advantages in terms of training and skill acquisition. BCI tools could enhance learning and memory processing, accelerating the training process and enabling personalized mission-specific training. As a result, soldiers could acquire and retain more information, improving their overall performance in the field [9]. In summary, the strategic advantage of cognitive enhancement in future warfare lies in its ability to improve decision-making speed, manage information overload, enhance interaction with AI and autonomous systems, and accelerate training. However, the potential challenges and ethical implications of its use must also be taken into consideration as we navigate into this future.

4.0 CONCLUSIONS

In conclusion, the potential application of human enhancement technologies such as genome editing and brain-machine interfaces (BCIs) in cognitive warfare presents both intriguing opportunities and significant challenges. These technologies offer the potential to enhance human cognitive capabilities, improve decision-making, and increase resilience, both in a military context and within the general population. While both technologies have significant potential, BCIs seem more likely to see military adoption in the near future due to a combination of technological readiness and fewer associated ethical challenges. However, their misuse also raises serious concerns, particularly in the realm of cognitive warfare where they might be used to deliberately deteriorate cognitive function or manipulate human behavior. The misuse of gene therapies for cognitive enhancement or deterioration is more likely to occur in somatic cells than in the germline. This is due to the practical challenges and ethical concerns associated with germline editing, although the landmark case of He Jiankui, who used CRISPR to create genetically modified embryos, highlights that this barrier is not insurmountable. Misuse of these technologies is also more likely to occur in contexts where there is both knowledge and resources available for using CRISPR and understanding the target traits. This emphasizes the importance of effective oversight and regulation of these technologies, particularly in research and healthcare settings. When considering the potential targets for genetic modification in cognitive warfare, traits that are controlled by a few genes are more likely to be targeted than complex ones due to the greater difficulty and uncertainty associated with manipulating multiple genes simultaneously. Despite the considerable technological, social, operational, and ethical challenges associated with genome editing and BCI, the potential benefits they offer in health and medical research could drive their legitimate use forward. This, however, could also increase the risk of dual use, where these technologies are repurposed for harmful ends.

As we move into the future, the crafting of specific regulatory strategies, potentially including an international regulatory body or treaty, will become increasingly crucial. Given the profound implications of these technologies, we must ensure the broader public is accurately informed and included in the dialogue. In parallel, our society must confront the risk of increasing disparities in access to these advancements and consider how to ensure equitable distribution of benefits. Furthermore, the integration of BCIs into cognitive warfare illuminates a new frontier of cybersecurity. Ensuring the security of these devices against hacking and unauthorized access will be of paramount importance. Lastly, as significant progress in genome editing and BCIs often originate from the private sector, these entities need to be held accountable for their developments. The ethical obligations of these companies must be part of the larger discourse, as their innovations can significantly shape the future of cognitive warfare and human enhancement.

Collectively, the complex interplay of technological progress, ethical considerations, and regulatory strategies demands a thoughtful, nuanced dialogue involving a wide range of stakeholders, including public citizens, scientists, policymakers, ethicists, and private sector entities. Through such collaborative and critical discussions, we can responsibly shape the future of cognitive warfare and human enhancement, ensuring these advancements serve the betterment of human society rather than its detriment. This continuous dialogue must remain a priority for further research and development endeavors in this dynamic and ethically charged field.

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