COGNITIVE BIOTECHNOLOGY

Altering the Human Experience

Alonso Bernal, Cameron Carter, Melanie Kemp,
Ujwal Arunkumar Taranath, Klinzman Vaz

JOHNS HOPKINS
WHITING SCHOOL of ENGINEERING

NATO OTAN

Table of Contents

Executive Summary

The ability to move your arm feels like a given. The movement is innate, unconscious, and even simplistic. However, it is only within the last decade that scientists have been able to accurately meld brain signals with machine interfaces to create mind-controlled prosthetics. Additionally, only in the last few years have they been able to make this flow of information bi-directional, creating prosthetics that can now feel sensation and send these feelings to the brain [1]. Our ability to decode the mind, and our ability to create computers which can handle this decoded data, are just emerging. Alongside these amazing opportunities come deep considerations for NATO about applications, strategies, and consequences. To help focus these considerations, this paper aims to identify, categorize, and assess these upcoming cognitive biotech innovations.

The term cognitive biotechnology is itself nebulous, being part of an emerging field. Our first objective in this paper is to define it as advancements affecting perception, attention, understanding, memory, and coordination. Furthermore, we then seek to classify these advancements by the method through which they enhance cognition through biochemical, physical, and behavioral means. These categorizations help track which fields of science these advancements are coming through: medical, engineering, and psychology, respectively, for example. Moreover, we then sought to classify these advancements by purpose in order to provide some framework for organization and application considerations. This led to the creation of the RAR (Recover, Augment, Replace) framework that will serve as the main organizational thread of this paper.

Recover encompasses the rehabilitation of cognitive deficits and current commercial technologies that deal with the creation of the bi-directional brain-computer interfaces and training apps and the stimulation of repressed neurons. Current research is being conducted on deeper stimulation and suppression of defective neurons, although there are also interesting avenues being explored in bi-directional interfaces on the senses more so than motor movement. The future of this category promises an enticing control of memories and the ability to stimulate deep regions of the brain through computers while simultaneously translating this information to be “downloaded” for further use.

Augment describes the enhancement of cognitive ability past the norm. Current commercial technologies include training applications, wearables that claim to boost cognition, and nootropic supplements. Experts are currently researching a range of transcranial current stimulations (TDCS) that impact the brain directly, as well as a whole slew of wearables with functions ranging from improving eyesight by orders of magnitude to the ability to translate speech and text in moments. The future of this category provides opportunities for the creation of enhanced soldiers beyond anything before seen. They will be trained through accelerated technology, given supernatural senses and high-tech wearables, and gifted with the ability of preternatural decision making.

Replace refers to the replacement of some human cognitive components with those of a computer, with the goal of seamlessly merging the two. Current commercial technology includes all forms of bi-directional interfaces, connecting humans to machines, computers, and even analyzing brain waves in their purest forms. Current research is focused on reading brain activity to map personal needs and specifications on actions such as sleep, to replace entire sensory connections and provide blind people with sight through computers, and to connect two minds that are apart by reading each one's thoughts. The future of this category promises to change how humanity connects and perceives their environment forever by providing the ability to instantly reach out to others without the need of speech, intimately understand each other, and pass the limitations that our human body places on our senses.

There are other technologies, still simply ideas, that are not receiving the same level of attention but could have deep impacts on the field of cognition. We have listed some examples, which are varied in objective and field of study, in the "Landscape Analysis" section. We also highlight the important ethical considerations that must follow a field as sensitive as human cognition. The opportunity for unintended consequences, privacy infringement, and abuse are present and must be deeply considered. Ultimately, advances in human cognition have the potential to be truly wondrous and transform the way we view the world and each other. There is still much progress to be made and some serious factors to consider. Yet, we believe NATO can grow the field into something exciting and amazing, not only for NATO countries, but for the world.

Problem Statement

As our understanding of human cognition advances, so too does our understanding of what "being human" means on a fundamental level. Revolutions in science and technology have already had far reaching consequences in human potential and behavior. Wonderous marvels of prosthetics and genetics have people brazenly asking if the era of "completely human" athletics is over [2]. Groundbreaking gene modification research has others wondering if the time will soon come where the taxonomic genus *Homo* becomes more crowded than ever expected [3].

Alongside these, however, come darker considerations as well. In the medical space, debates rage about whether CRISPR-Cas9, a cutting edge gene-editing tool, will be the savior of humanity or its doom [4]. The potential to alter humans on a basic level is intoxicating, but it is also rife with worries of designer babies and unforeseen consequences. On the technological front, inside basement laboratories (although tech shops might also be a fitting name) people experiment with metal implants (and their pain thresholds) to gain a glimpse of what it means to be beyond human. An underground market for implants and robotic modification blooms as people see the union between the physical and the digital as "inevitable" [5]. The operations, unregulated to the extent that they occur without the aid of anesthesia, promise an improved breed of human. Inevitably, they also risk the demarcation of the "unimproved" breed of human, with all the connotations this brings.

Recent advancements in the sciences of neurology, psychology, and cognition have already highlighted opportunities for the human mind itself to become unrecognizable. Some possibilities loom in the distant future, their exact shape and potential nebulous, while others are already haphazardly accelerating into the hands of everyday people. In order to be ready, we seek to identify, categorize, and determine the dangers and potentials of this upcoming revolution in cognitive biotechnology that promises to alter the human experience itself.

Categorization

Fields of Cognition

Intuitively, the word cognitive refers to the workings of the mind and the underlying neural physiology. Nick Bostrom, from the Future of Humanity Institute and noted author, has already segmented the cognitive field into five distinct domains:

- **Perception**: Acquisition of information
- **Attention**: Selection of information
- **Understanding**: Representation of information
- **Memory**: Retention of information
- **Coordination**: Guide behavior from use of information

Additionally, Bostrom identifies a few methods of cognitive enhancements including: Education, enriched environments, general health, mental training, drugs, transcranial magnetic stimulation (TMS), genetic modifications, prenatal enhancements, external hardware/software, brain-computer interfaces, and collective intelligence systems. While an impressive list in and of itself, this paper is from 2009 and is therefore not exhaustive enough for our purposes [6].

Methods of Enhancement

To get a better sense of the modern understanding of the methods of cognitive improvements, we referred to a 2018 paper by Martin Dresler from the American Chemical Society. Dresler broadens the methods into three larger categories that are non-specific enough to include a majority of most modern and future perceived possibilities for cognitive enhancement [7].

- **Biochemical**: Enhancements such as nutrition, natural remedies, drugs, and body derivatives.
- **Physical**: Enhancements such as implants, electrical/magnetic/optical/acoustic stimulation, and a variety of gadgets.
- **Behavioral**: Enhancements such as physical exercise, sleep, meditation, multilingualism, mnemonics, and computer training.

It is important to note that the categories and examples are kept broad in the interest of maintaining a complete reach. Therefore, while examples such as “sleep” can seem rudimentary, they can easily be brought to their extremes. For example, is there a method to perfect sleep patterns and have people rest exactly when they want? Is there a method to elongate the restfulness achieved from sleep, allowing people to sleep for smaller durations? There are broader questions and implementations hidden inside each of these categories that can be explored thoroughly in and of themselves.

These categorizations each deal with different main scientific disciplines. Biochemical enhancements involve pharmacology and biochemistry, physical enhancements with biomedical engineering, and behavioral with psychology and sociology. Sponsors of cognitive biotechnology can more easily identify which institutions and fields will yield the desired results and choose appropriately. However, on the topic of sponsorship, there is no clear distinction in these categories as to which technological fields should take priority. They also do not solidly place any of these enhancement methods in the purview of specific departments. In many ways, each method of enhancement is doing revolutionary work. To avoid command ambiguity and assist in decision making, we set out to create one more additional framework.

Forms of Enhancement

The Recover, Augment, and Replace (RAR) framework we have created focuses primarily on the use cases of biotechnology. This gives NATO a method to prioritize sponsorship and workshop the implementation of these technologies. Additionally, the separation of the various use cases of biotechnology allow different divisions of NATO to sponsor projects related to each specific need and follow through more directly. Additionally, the use cases have a certain temporal line in terms of market and implementation readiness. There is a general grand progression from Recovery to Replace that will allow for easier operational timeline management. Below are the outlines of each of the three categories we've created.

Recover

Cognitive recovery refers to the repair or rehabilitation of cognitive impairments, which are a common health problem that is disproportionately found in the military veteran population. The study of how to enhance these individuals' cognitive functions back to baseline is the beginning of many cognitive biotech innovations. The field is both ethically important and a good staging ground for projects that can be translated in some form into the augmentation use case. This is especially true since research indicates that recovery back to the norm for cognitive function is easier to achieve than enhancing beyond the "natural resting point" for such function [7].

Cognitive Impairment

Cognitive impairment refers to persistent deficits in the brain's ability to function effectively. People may experience challenges in the following areas [8]:

- **Attention:** Struggling with holding attention on one particular task or dividing attention across multiple tasks (fixating on one thing).
- **Memory:** Difficulty remembering and recalling information, particularly verbal material.
- **Processing speed:** Impaired response times, speech production, and interpretation of information.
- **Executing functions:** Having a hard time developing solutions to problems, producing plans, or listening critically to new information.

Depending on the severity and duration of cognitive impairment, consequences can negatively impact an individual's functioning in key areas including work, school, socialization, driving, and the management of money and medications. In severe cases, it can vastly limit an individual's independence and self-reliance. This leads to being significantly more reliant on others to accomplish daily tasks.

Current Commercial Biotechnologies

Traumatic brain injury (TBI) is a leading cause of death and disability today, especially in the lives of retired veterans and injured soldiers. As a result of TBI, 1.5 million persons die every year, and nearly 2% of the world population has a long-term or lifelong need for help in performing daily living activities [9]. A patient's condition during the first few weeks after a TBI is precarious and life-threatening. During such critical periods, an accurate neurological assessment is essential for predicting recovery, and the intelligence being applied for these applications is cognitive recovery technology. Rather than building artificial intelligence, enterprises are leveraging cognitive technologies to automate and enable a wide range of problem areas that require some aspect of cognition [10].

Learning

Companies such as Lumosity [11], BrainLeap [12], and Happify [13] have developed websites and mobile applications with cognitive games and training exercises that help develop speed, memory, attention, and problem-solving skills. These technologies utilize research on positive psychology, cognitive behavioral therapy (CBT), and mindfulness to create daily tasks and challenges. Some technology companies are also developing computer games with eye trackers to ensure focus in adults with ADHD/autism. Injured soldiers and retired veterans who have undergone brain injuries could use these technologies to recover from depression and PTSD (Post Traumatic Stress Disorder).

Brain-Computer Interface (BCI)

A BCI is a two-way link (a bidirectional interface) where one direction involves sending brain activity to a computer, and the computer translates brain activity into motor commands. Communication also occurs in the other direction where the computer sends information directly to the brain of the BCI user [14]. One of the applications of this technology is for soldiers with paralysis or amputation to control the movement of muscles, limbs, and prosthetics [15]. BCI could also be used for neuroimaging to map the brain and aid clinical diagnosis and treatment of cognitive disorders [16].

Therapeutic

Transcranial direct-current stimulation (tDCS) is a form of neuromodulation that uses constant, low direct currents delivered via electrodes on the head. This technology may be used to help patients with brain injuries or psychiatric conditions such as major depressive disorder. B-Temia is using tDCSs and AI in exoskeletons to provide support for joints [17]. Further research shows that these technologies may be used to send electric signals for blocking pain and recovering perception capabilities. Another significant application of this technology is to record the brain signals in the treatment of nervous system conditions. Companies such as Syncron [18] and Flow Neuroscience have been successful in this field [19].

Current Research

There has been innovative research taking place on electrical and magnetic stimulation technologies for treating neurological disorders. Depression naturally suppresses certain brain regions, and rTMS (repetitive transcranial magnetic stimulation) stimulates these affected areas to aid in returning to normal sensation. Recently, Johns Hopkins Hospital has been part of a select group that have extended this to dTMS (deep transcranial magnetic stimulation) [20]. This treatment is now able to reach deeper regions of the brain and can aid in PTSD recovery. The implications of such technology outside depression are still being investigated. Similarly, ultrasound waves are being used to part the Blood-Brain Barrier (BBB) to allow select substances through for viral gene therapy of Alzheimer's. Future research is focused on the finer tuning of this BBB parting to target cancers [21].

Other emerging recovery research includes an approach known as BrainHearing™ by Oticon. The technology focuses on supporting the way the brain makes sense of the sounds received from the ears. These hearing instruments use sophisticated processing that modifies only the parts of the signal that the individual ear does not hear well, giving the brain the most precise, purest possible signal to decode [22]. A possible entry point into supersonic hearing, such a device could help soldiers localize sound on the battlefield or distinguish between an approaching enemy, vehicle, or weapon.

Future of Cognitive Recovery

As cognitive biotechnologies such as Brain-Computer Interface (BCI) empower intelligent machines, and more, to think like human beings, human capabilities, reach, and knowledge will likewise undoubtedly increase beyond cyberspace. It is no longer about the replacement of man with machine, but about intelligence augmentation [23]. These future technologies could help NATO recover three assets: Retired veterans, injured soldiers and injured enemy soldiers.

Retired Veterans

Veterans are a prime example of people who would benefit from, and be useful for, research on cognitive recovery techniques. Their extensive combat experiences, high-intensity training skills, decision-making knowledge, and leadership qualities are valuable, but they usually dissipate after veterans retire from the service. BCI technologies could help the government take advantage of these skills by instantly recovering veterans' memories and knowledge to develop new combat strategies.

Another future domain for retired veterans would be the ability to effectively coach and mentor soldiers. We could predict tDCS, and BCI technologies developing ways to stimulate a person's cognitive abilities so they recover detailed information from memory. This could create new opportunities for the veterans to access crucial experiences from the past and later construct plans for training.

Injured Soldiers

The second application of future cognitive recovery would benefit injured soldiers. BCI technology is constructing links between software and the human brain to control exoskeletons and prosthetics. This technology would help disabled soldiers who lost their limbs during combat. Another future application would be to instantly restore a person's health or fatigue on the battlefield with the help of biotechnologies such as nootropics or supplements. A "health meter display," created through health data agglomeration, would allow soldiers to keep track of their readiness status and pre-emptively indicate the need for such interventions.

Therapeutic technology could also be explored in the fields of brain-sensing enhancement. Soldiers who suffer injuries on the battlefields could have the ability to increase their sensing capacity automatically such as threat recognition, improved vision, or amplified hearing abilities for maximum function. Optimally, to increase their chances of survival once wounded and limited in motion. Even better would be the potential to transfer their memory, location, and skills to a teammate instantly.

Injured Enemy Soldiers

A new spectrum of opportunities arises with recovering injured enemy soldiers for the benefit of allies. BCI could be used to track a person's memory on the computer and extract useful information. This coupled with machine learning and AI technologies could also help with advanced interrogation techniques to predict fake information.

We could also anticipate emerging technologies for memory erasure, which is selective artificial removal of memories or associations from the mind. Some of the techniques currently being investigated are drug-induced amnesia, selective suppression, and destruction of neurons [24]. Another application to this process is to erase an enemy soldier's memory to use them as a spy or an allied soldier by giving them a “clean slate.” As with most new technologies, the idea of being able to erase memories comes with many ethical questions and serious legislative and judicial implications.

Augment

Cognitive augmentation is a form of increasing cognitive function past the individual's natural baseline. Biotech cognitive augmentation is a rapidly growing space and involves anything that enhances the performance of soldiers on the front lines or decision makers at home. The development of preternatural cognitive abilities will have interesting implications, specifically in small teams that depend heavily on individual abilities. This form of enhancement includes training and exercises, decision making support, tactical operational abilities, awareness, and lethality. However, much of this space is still in the initial stages of research or ideation with a limited number of commercially viable products that could be implemented by NATO personnel.

Current Commercial Technologies

Today, much of the innovation surrounding cognitive enhancements consists of improving memory, attention, and coordination (reflexes). This is done primarily through cognitive training exercises and games on a phone or computer app such as those described in the Recover section. These apps, Luminosity and Happify have augmentation components in addition to their recovery ones [11][13]. However, these apps rely on wide audiences. The technology itself can be catered specifically toward recovery or augmentation for better results.

Several new technologies are also looking to improve memory, attention, energy, and learning through wearable tech and nootropics. Many of the wearables function by using electronic stimulation to enhance the brain's capacity to focus and retain information. Humm and Brain Co. are two examples that make use of patches and headbands to send small impulses through the brain that boost cognitive performance [25]. Nootropics companies, such as H.V.M.N. and TruBrain, work similarly to improve cognitive abilities, but do so by increasing the flow of oxygen and amino acids to the brain during periods of learning or training [26]. The current available technology has shown promising signs of where this field is moving but has yet to provide significant enhancements in cognitive performance.

Current Research

Since there has yet to be groundbreaking results in the areas of cognitive augmentation, most of the ideas and technology are still being researched and discovered. There has been interest in transcranial direct current stimulation (TDCS) shown in the release of wearable technology, but this is an area of ongoing research. Oxford and Stanford both have current research in affecting the flow on neurons by passing electric currents through the brain and nervous systems [27][28].

There is also significant R&D in the creation of new, more tangible, technologies to boost the effectiveness of soldiers. Especially in terms of language acquisition, vision, and lethality. The language barrier has always been a challenge, particularly in deployed environments, which is why hyper learning and instant translation are key developments that will help bridge the gap. Google and Microsoft are examples of larger players in this field. Both are developing translation technology for written and even spoken language that will have huge military implications once it becomes more refined. SYSTRAN, SDL, and Lionsgate are several other companies working in this field as well [29].

Improved visual capabilities is another area of cognitive augmentation that will have large military implications. These advancements range from increased optical zoom to color enhancements and personal HUD's that give individuals an advantage in harsh or unfamiliar environments. NuEyes is a company developing products that will grant optical magnification up to 12x as well as in-depth color contrast and text-to-speech capabilities [30]. Many other startups and organizations are developing equipment and armor for soldiers to be safer, more agile, and more able to react to their environment without compromising cognitive functions and effective decision making.

Future of Cognitive Augmentation

The current tech and research reveal in part where cognitive augmentation will be in the future, but there are some areas that have still not been discovered or researched enough. This is the section where we highlight what we believe to be the most impactful and influential areas of cognitive augmentation that will be present in the future based on what is currently being developed and what is yet to exist.

Education

From the current technology and research on memory and understanding, it is clear that education, specifically hyper learning processes and enhanced educational tools, will play a significant role in the future. We see evidence of this in the many companies developing TDCS devices, nootropics, and enhanced learning exercises. All with the aim to increase cognitive function and some targeted at making learning faster and more effective. This will become a necessity as our world continues to become increasingly interconnected with the advent of data streams and social media. The vision is that the future of education relies on a constantly available stream of information, leaving one aware of current political, social, and economic issues and events taking place. Efforts would also be aimed at the ability to learn skills and develop capabilities rapidly and transmit this information between individuals and groups.

The Future Soldier

A second field of cognitive augmentation could allow for some form of "super soldier" of the future. There are numerous companies developing and researching technology that knowingly, or unknowingly, will have significant military applications. These are cognitive enhancements that will 1) remove the unknowns from an environment and 2) eliminate the ability-based limitations on soldiers operating in those environments. This will allow for small teams or even individuals to be placed into any environment and be able to operate effectively without cultural, political, or physical limitations.

Some of the advancements we see addressing the unknowns in an environment are shown in examples of simple vision enhancements, personal HUD's that highlight threats or contain facial recognition, and information streams that relay current cultural or political tensions in a region. Ability-based limitations are already being analyzed to some extent, specifically with language advancements that are developing instant translation. There are also wearables and nootropics created to enhance energy, attention, and perception, which are crucial in deployed and unfamiliar environments.

Enhanced Decision Making

The third field that has seen a significant increase in attention in recent years is enhanced decision making, particularly through the support of AI and machine learning. However, this is still a new field and not fully understood, which leaves room for discovery of how this will be integrated into strategy, planning, and coordination by military and/or civilian leaders. AI also brings to the forefront the debate of creating automated processes versus fully autonomous systems. A constant goal of military organizations is to increase efficiency by automating processes to free up the workforce. However, they are still reluctant to relinquish the decision-making process to an autonomous system. This may be the correct response, but it still begs the question of how AI will support rapid responses and highlight threats to make military personnel more aware and precise in their judgements. AI will most certainly integrate into our systems and daily tasks and become a cognitive augmentation for decision-makers, but the question is to what extent will that be the case.

Replace

Cognitive replacement deals with substituting biological cognitive functions with that of a computer to enhance functions past the bounds of human potential. This is perhaps the most futuristic form of enhancement, with most research in replacing cognitive functions only just now developing or even nascent in nature. It is important to note that this form of enhancement does not completely remove human interaction, or else it would be simply another form of automation. This form of enhancement is speaking on the merger of human biology and mechanical application.

Replacing Cognitive Abilities

Replacing memories has been shown to be possible in some experimental conditions with some techniques being concentrated on drug-induced amnesia, destruction of neurons, selective memory suppression, and various other biotechnological advancements. While replacing human cognition entirely may seem futuristic now, some technological advancements and applications are making its likelihood more prominent.

Current Commercial Technologies

There have been advancing developments in the field of computational neuroscience that could be the key in achieving replacement of human cognition with the use of technology. At present, integration of cerebral and machine interfaces is the subject of research of several companies. The technology commercially available or to be derived in the future are as follows:

Brainwave interface (BWI)

Cognitive Behavioral Therapy for Insomnia (CBT-I) is widely considered by the medical community, including the ACP (American College of Physicians) and APA (American Psychological Association). Many people resort to pills to replace traumatic memories as well as insomnia. However, technology involving brainwave interfaces used to resolve difficulty sleeping has been developed and is commercially available. Implications could be extended to memory suppression and control.

Brain-machine interface (BMI)

BMI holds promise for the restoration of sensory and motor function and the treatment of neurological disorders, but clinical BMIs have not yet been widely adopted in part because modest channel counts have limited their potential [31]. This technology can be used for advanced interrogation but is still under the development and ideating phase, awaiting expertise from professionals of various backgrounds. The technology could prove extremely beneficial in altering memory and re-programming individuals but would be subject to ethical questioning.

Brain-computer interface (BCI)

Conditions such as blindness, paralysis, and mental illness, which today are considered untreatable, will be reframed as data problems with technological solutions using BCIs [32]. The technology is still in its development phase and aims to transfer human consciousness into a computational interface. This could prove useful in quick learning through data transmission to new learners. The technology could potentially be one of the first steps in the creation of human cyborgs, replacing human physical involvement completely.

Current Research and Companies

Dreem has developed a headband that measures brain activity and other biological signals throughout the night for a complete and accurate view of a user's sleep. Lightweight, flexible, and comfortable, the Dreem 2 headband also does not emit Wi-Fi or Bluetooth despite mobile app integration. Any brain data collected during its function is used to create a unique sleep formula – personalized, actionable insights designed specifically per customer [33]. Seeking to replace the natural human circadian rhythm, we foresee soldiers being able to fully rest as needed and improve their performance for the next day using data from the headband.

In terms of what most would think cognitive replacement to be, Paradromics envisions a future where data is exchanged effortlessly between brains and computers. They are developing neuroprostheses designed to help patients with disabilities such as blindness better navigate [34]. In the future, this technology could also be useful for sharing intel between soldiers and

commanders or for training and mentorship, as mentioned previously in Recover, between more experienced soldiers and new recruits.

Continuing along the lines of telepathy, Neurable provides non-invasive brain-computer interfaces that allows users to control software and devices using only their brain activity through wet EEG systems, continuous impedance, and signal quality monitoring [34]. Elon Musk's company, Neuralink, has also been developing technology with potential applications in this space; the device allows users to control computers and phones with their brains. As per Bloomberg's report, the device can currently "read" a rat's mind with the help of tiny electrodes implanted into the animal's neurons and synapses [35]. With further development, devices such as Neurable's and Neuralink's could prevent soldiers from having to be in the same physical location to control weapons or tanks, saving lives and reducing squad size.

Future of Cognitive Replacement

Technology developed for the replacement of human cognition is mostly under the development phase and subject to ethical consideration. However, on a positive ethical scale, it could be used to provide speech options to the paralyzed and save many lives. Timely gathering of information from injured personnel is crucial in deployed environments. In addition, war veterans experience tremendous post-traumatic stress and have vivid memories that cause abrupt and interrupted sleep routines, affecting mental and physical health. Treating PTSD through the replacement of traumatic memories would be an ideal usage of replacing human cognitive abilities. Transmitting consciousness by providing a platform for existence and decision making even after individuals are in coma or deceased is another enticing futuristic recommendation. Using chips that can measure temperature, pressure, movement, and other data that could warn you about a heart attack or stroke is the way the technology currently aims to move forward.

Landscape Analysis: New Opportunities

The three preceding sections have covered what our team has found to be the prevailing commercial options, as well as leading academic and medical research. However, there are a lot of missing pieces here in terms of the general opportunities presented by cognitive enhancement. Therefore, we have developed a landscape analysis to highlight some additional areas of cognitive enhancement for sponsorship and development by NATO. This is not meant to be an exhaustive list of technologies. It is meant only to highlight several potential applications in the world of cognition and defense.

Upcoming (Near Future)

- **Extraordinary Senses:** Electromagnetic vision outside the visual spectrum, additional color cones, and a sense of smell so advanced it can be diagnostic. Simply translating animal senses to humans will open many doors for human perception [36].
- **Memory Eraser:** Methods already exist to suppress or eliminate human memories; though, these tend to be invasive or traumatic. Current research into depression, however, might one day be flipped to suppress human emotion rather than excite it.
- **Micro-Expression Interrogation:** Algorithms and machine learning are advancing at an amazing pace. Recently, breakthroughs were able to determine if a smile was being faked [37]. Tweaks to this system to look for even more subtle hints and deeper insights would have far-reaching consequences in the art of data extraction.

Distant (Far Future)

- **Automatic Threat Recognition:** There are various firsthand accounts of individuals noticing subconscious signals of disaster before one occurs [38]. If these are true and science can enhance those signals effectively, soldiers might be able to develop a sixth sense for danger.
- **Avatar Simulations/Forms:** There are various situations in which human intervention is particularly dangerous. This has sparked an interest in drone development, but even so the military is leery of giving robots autonomous control over all functions. The solution is simple and already in the fledgling stage. A robot, an avatar, that is piloted completely by a

human through VR, AR, and/or neural technology. Seamless control will require advanced brain-computer interfaces to be developed [39].

- **Downloadable and Transferable Skill Knowledge:** Current work in brain-computer interfaces is paving the way for an exciting future where information can be transferred from a brain, to a computer, and back into another brain. The era of shareable skills, intuition, and experience may be approaching.
- **Freehand Emotional Manipulation:** There are several ways to currently manipulate human emotions. However, these usually require a certain level of familiarity with the subject and may take hours or other resources to succeed. Through algorithms, tDCS-like devices, or even brain-computer interfaces, one can easily imagine a future where manipulating emotions will be easy and at the dial of a button.
- **Algorithmic Human Memory and Intuition:** Human brains work differently than computer brains. This is the first lesson one learns while coding. For years, we have been trying to make computer brains more human. After all, human intuition and pattern recognition are unparalleled and will be for a while. Attempts to alter our physiology or interface with computers, however, will open the doors to making human brains more like computer brains as opposed to the other way around. Human pattern recognition paired with computer algorithms and sorting will be a wondrous combination.

Ethical Considerations

Clearly, altering natural human capabilities requires an in-depth investigation of the morals. How far can science go in supplementing our existing human capabilities before crossing into the territory of creating a hierarchy of normal humans vs. "superhumans?" The field of cognitive neuroscience is broad and continuously expanding, and the line between cognitive therapeutics and enhancement is thin. Bostrom defines therapeutics as "an intervention that is aimed at correcting a specific pathology or defect of a cognitive subsystem," whereas augmentations "improve a subsystem in some way other than repairing something that is broken or remedying a specific dysfunction" [6].

There has long been debate over whether enhancements would create people who are "better than normal" [40]. People commonly think of cognitive enhancements to be humans connected to AI-powered machines and computers. However, while cognitive enhancements do exist in the technological realm, there also exist pharmacological and psychological enhancements. More "conventional" methods such as mood and memory boosters, treatment for ADHD (Attention Deficit Hyperactivity Disorder), and mental training practices have all existed for years. The main distinction is that conventional methods of enhancement have more limited potential, have been in use for a longer time, been studied extensively, and are culturally accepted, whereas "unconventional" methods, such as technological advancements, have only been researched in a small pool of subjects. This brings us to the point that research should not shy away from the more unconventional methods, but rather they should be studied more extensively to create proper regulations for the following concerns, amongst others:

Safety and Privacy

Not only are there medical risks to consider with biotechnical modifications, but the integration of computers to brains also opens a discussion on data protection and privacy issues. There are also the more direct risks such as hacking and loss of control. With the ability to breach the privacy of someone's mind, who will be granted access to any data collected? How will such data be protected? What will be the correct course of action if access is abused or stolen by an enemy? There are numerous new considerations to be ironed out, and progress is not slowing down any time soon.

Medical Purpose

Even if the distinction between cognitive therapy and augmentation were to be clearly defined, there still exists ambiguity surrounding the circumstances of their usage. Some non-medical techniques, such as psychological treatments and wearables, can still have medical effects. Medications that are currently on the market that provide enhancement, such as Alzheimer's or ADHD medications, have only been approved because they treat existing conditions. Would the non-medical methods then follow the regulations already set by the medical community or should there be a new set of rules drawn up for enhancement methods? Will these enhancements only be provided to help the weak improve, or will they be an extension of humans to interact with the environment?

Personal Autonomy vs. National Security

Perhaps one of the most important ethical issues to discuss in this paper is where to define the boundary of personal autonomy and national security. In general, people feel pressured to remain competitive in their daily lives. The introduction of techniques to make someone cognitively "better" will only exacerbate this desire. Competition is even more pronounced in a military context. Based on the Uniform Code of Military Justice, soldiers are "required to accept medical interventions that make them fit for duty" [41]. If a soldier does not accept enhancements, or similarly does not volunteer for them, is he "violating" his oath to protect the nation's security by not performing at his best? Perhaps even allowing a soldier full autonomy in these decisions to accept enhancements runs the risks of bias, dependency, abuse, or self-destructive behavior.

Conclusion

It's interesting to think back to the times when we thought the advanced sci-fi technology that we saw in movies were too far-fetched to become reality. However, now we live these scientific advancements. From landing on the moon, to live video calling, and even Marty McFly's self-lacing shoes, we are now left to question what further progress will be made and what kind of impact they will have [42]. NATO and the military serve many functions, and the benefits to be gained when it comes to technological advancements are endless, especially in the field of cognitive enhancements. In order to understand what the needs of further developments in this space are, we first sought to investigate what products and research already exist – both with and without direct military applications.

We completed primary market research by examining current research and technologies, then categorized each based on 1) the core faculties of cognition it affects and 2) the method(s) of enhancement it utilizes. From here, we curated our own categorization, the RAR framework, to analyze what exists, realize what still needs to be developed, separate these into use cases, and recommend what further actions should be taken to actualize these developments. The following are some subjective interesting fields of study we've identified in the RAR framework. We posit that NATO could partner with organizations such as the Johns Hopkins Applied Physics Laboratory, Johns Hopkins Hospital, and Harvard's Department of Psychology in order to lead and develop the relevant technologies and fields of study. Regardless of the direction, it is our belief that NATO can pilot these advancements in a direction that will be beneficial to the alliance and even to humankind itself.

Recover

Brain-computer interface methods have been rapidly developing technologies for controlling machines and prosthetics with the brain's help. The current research into artificial sensory feedback and brain-mapping have immense potential in terms of recovery opportunities. NATO could leverage these technologies to explore options on secondary assets such as retired veterans and injured soldiers. The extraction of crucial information through memory restoration will yield dividends in all sorts of combat and command scenarios. BCI technologies also have the potential to one day transfer one's muscle memory and skills to another human being or computer. The collaboration of BCI and dTMS will certainly have crucial applications for recovering cognitive abilities in human beings.

Augment

Education and learning as disciplines have remained relatively stagnant through the centuries. However, as we begin to learn more about the human mind and cognition, the discussion about how we learn and understand information is being brought up and questioned once again. There are already companies developing memory and attention improvement technology and methods. The aim being to reach a state of “hyper learning.” As the information space and big data continue their rapid growth, the future is going to require ways to understand and synthesize this information quickly and effectively in order to better educate and advise students, leaders, and professionals. Education of the future may be seen simply as information transfer. This field has already shown increased attention in recent years and appears to be on a steep trajectory that will have significant implications not only in the academic world, but the military and civilian worlds as well.

Replace

As we look beyond automating human capabilities, we seek ways to replace our own cognitive abilities with computers to maximize our efforts beyond human potential. Brain-computer interface could be used towards development of cyborgs, human activity using machines, providing injured soldiers with computational mechanical prosthetics, or even using machines to control human interactions. Ideas of replacing human speech such as "conceptual telepathy," where two people can communicate electronically by thinking at each other instead of writing or speaking, have promising applications in almost every aspect of human life [35].

New Opportunities

Subversion and subterfuge have been the operational code of conduct for warfare and terrorism in the last few decades. The recent machine learning breakthroughs could produce much in terms of potential for this field. For example, the idea of identifying, categorizing, and reading micro-expressions in the face invisible to the naked eye will prove invaluable in efforts to combat insidious threats. Imagine being able to sit across from a terrorist and listing out words, only for a program to tell you detailed conclusions about their operations from the terrorist's uncontrollable micro-twitches. Imagine zooming in on a masked soldier in Ukraine and being able to tell through micro-expressions whether they were Russian soldiers or insurgents. Investment into face scanning algorithms, and a direction as to what these algorithms are searching for, will revolutionize how nations deal with espionage and terrorist threats.

References

[Cover] Cedars-Sinai Medical Center. *'Error Neurons' Play Role in How Brain Processes Mistakes*, Cedars-Sinai Medical Center, 4 Dec. 2018, www.cedars-sinai.org/newsroom/error-neurons-play-role-in-how-brain-processes-mistakes/.

[1] Wilde, Johanna. "Mind-Controlled Arm Prostheses That 'Feel' Are Now a Part of Everyday Life." *ScienceDaily*, Chalmers University of Technology, 30 Apr. 2020, www.sciencedaily.com/releases/2020/04/200430110321.htm.

[2] Enriquez, Juan, and Steve Gullans. "Genetically Enhanced Olympics Are Coming." *Nature*, 19 July 2012, www.nature.com/articles/487297a.pdf?origin=ppub.

[3] Ward, Peter. "What May Become of Homo Sapiens." *Scientific American*, 1 Nov. 2012, www.scientificamerican.com/article/what-may-become-of-homo-sapiens/.

[4] Licholai, Greg. "CRISPR's Potential and Dangers: Is CRISPR Worth the Risk?" *SciTechDaily*, Yale University, 22 Aug. 2018, scitechdaily.com/crisprs-potential-and-dangers-is-crispr-worth-the-risk/.

[5] Booton, Jennifer. "How I Became a Cyborg and Joined an Underground Medical Movement." *MarketWatch*, 26 Dec. 2016, www.marketwatch.com/story/i-joined-an-underground-medical-movement-but-had-to-become-a-cyborg-to-do-it-2016-11-15.

[6] Bostrom, Nick, and Anders Sandberg. "Cognitive Enhancement: Methods, Ethics, Regulatory Challenges." *Nickbostrom*, Springers Science+Business Media, 19 June 2009, nickbostrom.com/cognitive.pdf.

[7] Dresler, Martin, et al. "Hacking the Brain: Dimensions of Cognitive Enhancement." *ACS Chemical Neuroscience*, vol. 10, no. 3, 14 Dec. 2018, pp. 1137–1148., doi:10.1021/acschemneuro.8b00571.

[8] "Office of Mental Health." *Dealing with Cognitive Dysfunction*, 2006, omh.ny.gov/omhweb/cogdys_manual/cogdyshndbk.htm.

[9] Oh, HyunSoo, and WhaSook Seo. “Functional and Cognitive Recovery of Patients With Traumatic Brain InjuryPrediction Tree Model Versus General Model.” *Critical Care Nurse*, American Association of Critical-Care Nurses, 1 Aug. 2009, aacnjournals.org/ccnonline/article-abstract/29/4/12/13548/Functional-and-Cognitive-Recovery-of-Patients-With?redirectedFrom=fulltext.

[10] Walch, Kathleen. “Why Cognitive Technology May Be A Better Term Than Artificial Intelligence.” *Forbes*, Forbes Magazine, 23 Dec. 2019, www.forbes.com/sites/cognitiveworld/2019/12/22/why-cognitive-technology-may-be-a-better-term-than-artificial-intelligence/#47d6b73d197c.

[11] “Lumosity Brain Training: Challenge & Improve Your Mind.” *Lumosity*, www.lumosity.com/en

[12] “Controlling Machines with Brain.” *Neurable INC*, 3 June 2019, www.neurable.com/.

[13] “Overcome Negative Thoughts, Stress, and Life's Challenges!” *Happify.com*, my.happify.com/.

[14] “The Introductory Guide to BCI (Brain-Computer Interface).” *EMOTIV*, 9 Apr. 2020, www.emotiv.com/bci-guide/.

[15] “Controlling a Prosthesis with Your Brain.” *ScienceDaily*, ScienceDaily, 6 Feb. 2017, www.sciencedaily.com/releases/2017/02/170206084904.html

[16] Alkawadri R. Brain-Computer Interface (BCI) Applications in Mapping of Epileptic Brain Networks Based on Intracranial-EEG: An Update. *Front Neurosci*. 2019;13:191. Published 2019 Mar 27. doi:10.3389/fnins.2019.00191

[17] “B-Temia Human Augmentation Systems.” *B*, www.b-temia.com/who-we-are/.

[18] “Synchron.” *Untitled*, www.synchronmed.com/.

[19] “Medication-Free Depression Treatment at Home.” *Flow Neuroscience*, flowneuroscience.com/.

[20] Mennitto, Donna. *Transcranial Magnetic Stimulation (TMS) at The Johns Hopkins Hospital in Baltimore, Maryland*, 5 Feb. 2019, www.hopkinsmedicine.org/psychiatry/specialty_areas/brain_stimulation/tms/.

[21] “Focused Ultrasound Opening Brain to Impossible Treatments.” *UVA Health Newsroom*, 6 May 2020, newsroom.uvahealth.com/2020/05/06/focused-ultrasound-opening-brain-to-impossible-treatments/.

[22] “Hearing Aids, Information on Hearing Loss and Tinnitus.” *Oticon*, www.oticon.com/.

[23] Pandya, Jayshree. “Emerging Trends In Cognitive Systems.” *Forbes*, Forbes Magazine, 17 Apr. 2019, www.forbes.com/sites/cognitiveworld/2019/04/08/emerging-trends-in-cognitive-systems/#70dc937c29e3.

[24] Chan, Jason C K, and Jessica A LaPaglia. “Impairing existing declarative memory in humans by disrupting reconsolidation.” *Proceedings of the National Academy of Sciences of the United States of America* vol. 110,23 (2013): 9309-13. doi:10.1073/pnas.1218472110

[25] “Focus Headband.” *BrainCo*, 3 Jan. 2020, www.brainco.tech/technology/.

[26] “Brain Food Science.” *TruBrain*, www.trubrain.com/pages/brain-food-science.

[27] Hogenboom, Melissa. “Warning over Electrical Brain Stimulation.” *BC News*, BBC, 24 Aug. 2014, www.bbc.com/news/health-27343047.

[28] Selimbeyoglu, Aslihan, and Josef Parvizi. “Electrical Stimulation of the Human Brain: Perceptual and Behavioral Phenomena Reported in the Old and New Literature.” *Frontiers*, Frontiers, 2 May 2010, www.frontiersin.org/articles/10.3389/fnhum.2010.00046/full.

[29] Schwartz, Karen. “The Latest in Translation Devices.” *The New York Times*, The New York Times, 7 Nov. 2019, www.nytimes.com/2019/11/07/travel/the-latest-in-translation-devices.html.

[30] “Visual Prosthetics in US: US Visual Prosthetics: Visual Prosthetics United Sta.” *NuEyes*, www.nueyes.com/.

[31] Musk, E., & Neuralink. (2019, January 01). An integrated brain-machine interface platform with thousands of channels. Retrieved August 31, 2020, from https://www.biorxiv.org/content/10.1101/703801v3

[32] Paradromic Technology. (2019, December 20). Retrieved August 31, 2020, from https://paradromics.com/our-technology/

[33] Sleep, finally. (n.d.). Retrieved August 31, 2020, from https://dreem.com/

[34] Neurable Technology. (2019, July 15). Retrieved August 31, 2020, from https://www.neurable.com/technology

[35] Shankland, S. (2020, August 29). Elon Musk shows Neuralink brain implant working in a pig. Retrieved August 31, 2020, from https://www.cnet.com/news/elon-musk-shows-neuralink-brain-implant-working-in-a-pig/

[36] Kelley, Laura. "Inside the Colourful World of Animal Vision." *TheConversation*, 6 Nov. 2014, theconversation.com/inside-the-colourful-world-of-animal-vision-30878.

[37] "How Can You Reliably Spot a Fake Smile? Ask a Computer." *ScienceDaily*, University of Bradford, 29 July 2019, www.sciencedaily.com/releases/2019/07/190729111239.htm.

[38] Bazian. "Humans Have 'Super Spidey Sense' for Danger Claim." *NHS*, UK National Health Service, 31 July 2012, www.nhs.uk/news/mental-health/humans-have-super-spidey-sense-for-danger-claim/.

[39] Weinberg, Neal. "How Robotic Avatars Will Become Ubiquitous in the Future." *Robotics Business Review*, 16 July 2019, www.roboticsbusinessreview.com/events/how-robotic-avatars-will-become-ubiquitous-in-the-future/.

[40] Farah, Martha J. "Emerging Ethical Issues in Neuroscience." *Nature Neuroscience*, vol. 5, no. 11, 2002, pp. 1123–1129., doi:10.1038/nn1102-1123.

[41] Tennison MN, Moreno JD (2012) Neuroscience, Ethics, and National Security: The State of the Art. PLOS Biology 10(3): e1001289. https://doi.org/10.1371/journal.pbio.1001289

[42] Vincent, James. "Nike's Self-Lacing Sneakers Finally Go on Sale November 28th." *The Verge*, The Verge, 21 Sept. 2016, www.theverge.com/2016/9/21/12998474/buy-nike-self-lacing-shoes-hyperadapt-1.

APPENDIX A: Company/Research Organizational Matrix

The matrix linked here lists companies and current research in the areas of cognitive biotechnology. In the first column, each company and research are listed with a brief description of the technology being developed. They are categorized by color based on the method of cognitive enhancement: Therapeutic (blue), Learning (orange), Nootropics (purple), Brain-computer interface (green), and Transcranial Direct Current Stimulation (TDCS) (yellow).

The companies and research are then labeled by the different methodologies of enhancement, Behavioral, Physical, and Biochemical, and the specific type of enhancement they are striving to achieve denoted with an "x" if it applies to that company.

The type of enhancements, Perception, Attention, Memory, Understanding, Behavior/Coordination, are listed underneath each of the methodologies. The companies and research are also analyzed on a considerably basic scale of 1-3 measuring Maturity/Development, Cost, and Ethical Considerations. Descriptions of the scale for each rating is detailed below each category.

APPENDIX B: RAR Organizational Matrix

The matrix linked here organizes the companies and research along our classifications of Recover, Augment, and Replace to describe the types of enhancement and potential target audiences along the first column.

The first row classifies the companies based on the type of enhancement detailed in our previous matrix (Appendix A): Perception, Attention, Memory, Understanding, and Behavior and Coordination.