Emerging Neuroscience and Technology (NeuroS/T): Current and Near-Term Risks and Threats to NATO Biosecurity

James Giordano PhD

"The key to victory or defeat in war is people…the key to people lies in the brain"[1]

Introduction: Progress and Viability of Neuroscience and Technology (NeuroS/T)

Neuroscience employs a variety of methods and technologies to evaluate and influence neurologic substrates and processes of cognition, emotion, and behavior. In general, brain science can be either basic or applied research. Basic research focuses upon obtaining knowledge and furthering understanding of structures and functions of the nervous system on a variety of levels by employing methods of the physical and natural sciences. Applied research seeks to develop translational approaches that can be directly utilized to understand and modify the physiology, psychology, and/or pathology of target organisms, including humans. Neuroscientific methods and technologies (neuroS/T) can be further categorized as those used to assess, and those used to affect the structures and functions of the nervous system, although these categories and actions are not mutually exclusive. For example, the use of certain drugs, toxins, and probes to elucidate functions of various sites of the central and peripheral nervous system can also affect neural activity.

NeuroS/T is broadly considered to be a natural and/or life science and there is implicit and explicit intent, if not expectation to develop and employ tools and outcomes of research in clinical medicine. Given the goals of medicine to elicit right and "good" treatment in patients' best interests, neuroS/T research is conducted in accordance with an undergirding maxim of non-harm (non-maleficence). However, absence of harm cannot always be assured for the use

[1] Jin H, Hou L-J, Wang Z-G (2018). Military brain science – How to influence future wars. *Chinese J Traumatology*. 21: 277-280.

of research findings and/or products. This latter point has become somewhat contentious and is the focus of this report as regards the potential and actual uses of neuroS/T research that are distinct from intended applications, and/or specifically intended to incur demonstrably threatening consequences to individual and public health and/or environmental integrity. Such applications of scientific and technological research are referred to as "dual use".

Working Definition of Dual-Use[2]

Axiomatically, dual-use research refers to findings or products of scientific and/or technological studies that can be employed for more than one purpose. According to this definition, neuroscientific techniques, technologies, and information could be used for medical as well as non-medical (educational, occupational, lifestyle, military, etc.) purposes. Of particular note is that this formal, albeit general, definition of dual use does not indicate or suggest that such secondary uses incur burdens, risks, or harms beyond those anticipated for primary intent. Nor is it particularly useful, since everything that could be employed for more than one purpose would fall under "dual use". To reduce ambiguity, increase specificity, and highlight potential risks and threats of harm, the United States (U.S.)' National Institutes of Health Office of Science Policy (OSP) established the classification of "Dual Use Research of Concern" (DURC) that entails life science research that can be anticipated or expected to afford information, technologies, and/or products that can be engaged to incur deleterious consequences to public health and safety, agriculture, animals, environment, and/or national security. Intrinsic to this definition is the possibility, if not likelihood, that such research outcomes could be usurped to illicit harm. As well, classification of DURC includes the use of tools and technologies that may pose risk and threat of harm as a consequence of inadvertent misuse (e.g., through laxity in laboratory containment, contamination, etc.). Of note is that although military and national security applications are certainly implied by, if not constituent to the OSP definition, and thus would warrant consideration and address, they are not specifically explicated.

A still more focused definition, which more stringently identifies such applications and aims, is provided by the European Commission, which classifies dual-use goods, products, and technologies as those "…normally used for civilian purposes, but which may have military applications." However, this definition does not either specify precisely which types of uses within the military would pose particular concerns that might be different from, or exacerbative

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[2] Giordano J, Evers K. (2018). Dual use in neuroscientific and neurotechnological research: A need for ethical guidance. *Ethics and Integrity in Health and Life Sciences Research – Advances in Research Ethics and Integrity*.4: 129-145.

to other occupational applications (e.g., cognitive, emotional, or behavioral alterations) that could pose risk or threat of harm. So, for example, would off-label use of neuropharmaceuticals or forms of non-invasive brain stimulation (NIBS) to optimize performance of military personnel elicit different concerns given their potential engagement in national security, intelligence, or warfare operations? Here, while performance optimization represents a proximate goal, it could also be viewed as means instrumental to warfare.

Of course, it could also be argued that such uses, performance enablements, and resulting capabilities could (and perhaps should) be used in intelligence and/or diplomatic operations to mitigate and subvert aggression, violence, and conflict. This remains a topic of ongoing debate. Of more focal concern are uses of research findings and products to directly facilitate the performance of combatants, the integration of human-machine interfaces to optimize combat capabilities of semi-autonomous vehicles (e.g., drones), and development of biological and chemical weapons (i.e., neuroweapons). The potential for such uses is sustained by historical examples of military adoption of scientific and technological developments, dating at least to the middle of the nineteenth century.

The increasing role of governmental support in both academic and industrial scientific enterprises during the early twentieth century fortified the establishment of unambiguous programs of military and intelligence use(s) of science and technology, inclusive of iterative developments in chemistry and biology that could be used to affect the nervous system. Furthermore, given that a formal definition of a weapon is “a means of contending against others”, it becomes difficult to specify whether and which neuroscientific tools and technologies, when employed in military contexts, can and should be regarded as weapons. Moreover, if a broad definition of dual use or DURC is exercised, then the criterion of individual or public safety or harm might necessitate a more granular address and analysis of offensive or defensive applications, questions of protection versus harm, and a more thorough exploration of means and ends, writ large. Absent such conceptual clarification, categories of dual use and DURC could be considered vague and construed as either too broad or too narrow. This could incur practical as well as philosophical implications.

More sober efforts have been reflected in advisory reports from the U.S. National Research Council commissioned by agencies including the U.S. Army and Defense Intelligence Agency during the early 2000s. These reports included recommendations for the military and intelligence community to identify and pursue neuroS/T that could be developed for operational use. This was prescient; for while a 2008 U.S. National Academies Report, *Emerging Cognitive Neuroscience and Related Technologies*, was somewhat cautious in its view of the operational utility of brain science, subsequent reports, including a number of Pentagon whitepapers, have acknowledged that neuroscientific techniques and technologies have high potential for operational use in a variety of security, defense and intelligence enterprises. These papers also advocated the need to address current and near-term ethical, legal, and social issues generated by such use. A subsequent report by the National Academies in 2014, *Emerging and Readily Available Technologies and National Security: A Framework for Addressing Ethical, Legal and Societal Issues,* reflected this view, and the importance of ethical engagement. At present, operationally viable products of brain science include microbiological agents, toxins, drugs, devices, and data. Certain microbiological agents, toxins and chemicals are regulated and restricted by international policies, conventions, and treaties (such as DURC policies, and the Biological and Toxin and Weapons Convention (BTWC), and Chemical Weapons Convention (CWC); however, other substances (including novel agents that can be created using new tools of molecular biology), devices, and data, are not. Thus, neuroS/T is not wholly regulated and governed, and is therefore viable for use in military, intelligence, and political initiatives and operations.

Military and Intelligence Use of NeuroS/T[3]

The use of neuroS/T for military and intelligence purposes is realistic, and represents a clear and present concern. Illustratively, a 2008 report by the *ad hoc* Committee on Military and Intelligence Methodology for Emergent Neurophysiological and Cognitive/Neural Science Research in the Next Two Decades by the National Research Council of the US Academy of Sciences claimed that neuroscience and technology, while possessing potent capabilities, were not as yet demonstrably employable in military operations. However, by 2014, the Committee's subsequent report asserted that neuroscience and technology had matured considerably and were being increasingly considered, and in some cases evaluated for operational use in security, intelligence, and defense operations. This evaluation reflected a 2013 Nuffield Council Report, and a series of white papers by the Strategic Multilayer Assessment (SMA) Group of the Joint Staff of the Pentagon that illustrated the viability and value of the brain sciences to security, intelligence, and military operations (for overviews of, and access to reports, see: http://nsiteam.com/sma-publications/).

In large part, the iterative recognition of the viability of neuroscience and technology in these agenda reflects the pace and breadth of developments in the field. Although a number of nations have pursued, and are currently pursuing neuroscientific research and development for military purposes, perhaps the most proactive efforts in this regard have been conducted by the

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3 Giordano J. [ed.] (2015) *Neurotechnology in National Security and Defense: Practical Considerations, Neuroethical Concerns*. Boca Raton: CRC Press.

United States Department of Defense; with most notable and rapidly maturing research and development conducted by the Defense Advanced Research Projects Agency (DARPA) and Intelligence Advanced Research Projects Activity (IARPA). To be sure, many DARPA projects are explicitly directed toward advancing neuropsychiatric treatments and interventions that will improve both military and civilian medicine (e.g., Systems'-based Neurotechnologies for Emerging Therapies – *SUBNETS*; Restoring Active Memory – *RAM*; Next Generation Non-invasive Neuromodulation – *N3*; etc.; see: www.darpa.mil, for overview). Yet, as represented by Table 1, it is important to note the prominent ongoing – and expanding – efforts in this domain by NATO European and trans-Pacific strategic competitor nations.

Table 1. Representative Competitive Research Programs in NeuroS/T for Military/Intelligence Applications: China and Russia

Country	Major Research Institutions and Funding Resources	Research Themes
China	• National Natural Science Foundation of China • Ministry of Science and Technology (MOST) • Institute of Neuroscience (ION) of the Chinese Academy of the Sciences (CAS) • Chinese Society for Neuroscience • Second Military Medical University • Third Military Medical University • Fourth Military Medical University in Xi'an o Institute of Neurosciences • Zhujiang Hospital, Institute of Neuromedicine Partners • Beijing Society for Neuroscience • Neuroscience Research Institute, Peking University • IDG/McGovern Institute for Brain Research at Peking University • Beijing Normal University, National Key Laboratory of Cognitive Neuroscience and Learning • East China Normal University –School of Psychology and Cognitive Science • The Translational Neuroscience Center of West China Hospital of Sichuan University	• "Bio-chips" and biotechnology • Trauma • Neuro-degeneration • Tumor biology • Pain and analgesia • Drug abuse and addiction
Russia	• Russian Foundation for Advanced Research Projects o Laboratory of Neurotechnology Perception and Recognition with focus areas • Russian Academy of the Sciences o Institute of Higher Nervous Activity • 30th Central Scientific Research Institute, Ministry of Defense • State Research Center of Virology and Biotechnology (VECTOR)	• Neurotechnology • Integrated Biosystems • Memory, perception and recognition • Public health and safety • Neurotrauma

As the 2008 National Research Council report stated, "… for good or for ill, an ability to better understand the capabilities of the body and brain… could be exploited for gathering intelligence, military operations, information management, public safety and forensics". To paraphrase Aristotle, every human activity and tool can be regarded as purposed toward some definable "good". However, definitions of "good" may vary, and what is regarded as good for some may present harm to others. The potential for neuroS/T to afford insight, understanding, and capability to affect cognitive, emotional, and behavioral aspects of individuals and groups render the brain sciences particularly attractive for use in security, intelligence, and military/ warfare initiatives.

To approach this issue, it is important to establish four fundamental premises.

- First, neuroS/T is, and will be increasingly and more widely incorporated into approaches to national security, intelligence gathering and analysis, and aspects of military operations.
- Second, such capabilities afford considerable power.
- Third, many countries are actively developing and subsidizing neuroS/T research under dual-use agendas or for direct incorporation into military programs (see Table 1).
- Fourth, as noted in both 2008 and 2014 National Academies' reports, these international efforts could lead to a "capabilities race" as nations react to new developments by attempting to counter and//or improve upon one another's discoveries.

This type of escalation represents a realistic possibility with potential to affect international security. Such "brinksmanship" must be acknowledged as a potential impediment to attempts to develop analyses and guidelines (that inform or prompt policies) that seek to constrain or restrict these avenues of research and development.

Neuroscientific techniques and technologies that are being utilized for military efforts include:

1. Neural systems modelling and human/brain-machine interactive networks in intelligence, training and operational systems;
2. Neuroscientific and neurotechnological approaches to optimizing performance and resilience in combat and military support personnel;
3. Direct weaponization of neuroscience and neurotechnology.

Of note is that each and all may contribute to establishing a role for brain science on the twenty first century battlescape.

Military and Intelligence Personnel Performance Optimization: Historical Background[4]

Drugs

Warfighters have long used myriad substances both to fortify performance of military tasks and to cope with operational stressors. Alertness, wakefulness, and focus – key decision-making capacities of a warfighter – have been enhanced for centuries. An ephedrine-containing herb stimulated the senses of guards on China's Great Wall, just as coca leaves did for Incan fighters. Bavarian soldiers used cocaine during the First World War; amphetamines were widely used by the German armed forces during World War II, and other stimulants, referred to as "go pills," have been utilized – in varying degrees – by military and intelligence personnel in several operations thereafter.

Warfighters have even used hallucinogens and intoxicating combinations of psychoactive herbs to enhance their combat effectiveness, or at least the appearance of ferocity. Turks reportedly used opium to enhance wartime bravery in the 1500s. Consumption of *amanita muscaria*, a psychoactive and hallucinogenic mushroom, reportedly facilitated the "berserker" rage characteristic of Viking raids. South African tribal warriors smoked dagga, a type of cannabis, in combination with the consumption of other herbs to enhance fearlessness and insensitivity to pain.

Not only have warfighters used substances to enhance capacities to *engage* in combat, the history of warfare is rich with examples of warriors using substances to *disengage* from combat. In this latter regard, U.S. warfighters have recently used "no-go pills" to induce rest in preparation for, or in recovery from, combat. These interventions foreshadow ongoing research on drugs like propranolol, which could ultimately enable warfighters to disengage from combat without having formed traumatic memories.

Devices

The history of neuromodulation via electricity and magnetism also dates back centuries, if not millennia. Scribonius Largus, an ancient Roman physician, wrote the earliest known account of neurostimulation. As a headache remedy he described the apparent benefit of application of an electric fish to the scalp. Much more recently, 18th century scientists demonstrated the therapeutic potential of transcranial electric current and the electrical stimulation of muscle contractions. For the following two centuries, researchers attempted to treat various mental conditions with electric current, but success varied. Electroconvulsive therapy (ECT) was used

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4 Tennison M, Giordano J, Moreno J. (2017). Security threat versus aggregated truths: Ethical issues in the use of neuroscience and neurotechnology for national security. In: Illes J, Hossein S (eds.) *Neuroethics: Anticipating the Future*. Oxford: Oxford University Press, pp. 531-553.

to treat depression from the 1930s through the present. And deep brain stimulation (DBS), emerged in the 1980s as a treatment for Parkinson's and other movement disorders. More recently, advances in the hardware, placement, and control of DBS systems have prompted applications of this technique in the treatment of other neurological and psychiatric conditions. As well, ongoing research aimed at developing less- or non-invasive methods of implantation of indwelling devices and systems (such as DARPA's N3 project) is establishing a basis for broader consideration of using DBS to affect cognition, emotion, and behavior in order to optimize task performance (inclusive of those tasks focal to military and intelligence operations).

As the 20th century came to a close, researchers rediscovered the potential of applying low-level electrical current through the skull to affect the brain and its functions. Types of transcranial electrical stimulation (tES) have been used to modulate cortical excitability. In contrast to DBS, tES does not "stimulate" neurons by forcing or blocking their action potentials; rather, it "modulates" neurons by increasing or decreasing their threshold to fire. Studies have focused on tES's effects on neuroplasticity and the neurological substrates of cognition and motor activity. Although the safety of tES has been demonstrated, the current understanding of its efficacy for enhancement is incomplete. Some studies suggest that tES "can enhance cognitive processes occurring in targeted brain areas," but other scientists have failed to replicate this finding. Recent analyses reveal that "context matters", and the type(s) and extent of effects that can be elicited by tES strongly depend upon setting, and the neuro-cognitive state of the subject. As well, recreational tES devices are available on the consumer market and both clinical and direct-to-consumer tES technologies are of growing interest and potential utility to the military.

Magnetism is also used to manipulate neurological functions. Technologies include magnetic seizure therapy and transcranial magnetic stimulation (TMS). Approved to treat major depression, TMS may have additional applications for enhancement. In 2009, the U.S. National Research Council identified TMS as a wakefulness enhancement for the U.S. Army. Similarly, DARPA and the U.S. Army funded studies of wearable, helmet-borne devices to affect neurological function through the delivery of patterned ultrasound pulses.

Brain-machine interfaces (BMIs, also known as brain-computer interfaces – BCIs) constitute another major area of military neurological device research. BMIs can translate neurological signals into inputs for computers or machines, or vice versa. BMIs have potential for therapeutic breakthroughs in civilian and military medicine, and military and intelligence operational applications. BMIs attached to robotic arms have been employed to articulate prostheses using neurological output. Current DARPA research focuses upon fortifying feedback between the brain and prostheses to afford tactile feedback, such as pressure and temperature, from sensors in the prosthesis.

The DARPA AugCog program (short for "Augmented Cognition"), sought to fully integrate neurocognitive capacities and sensory perceptions with yoked input and control from combat vehicle environments. As computers monitor working memory, attention, executive function, and sensory input, military and intelligence personnel can sustain real time information about cognitive load, in order to more effectively manage and direct neurological functions and capabilities. Although the titular AugCog program has ended, similar, and more capable and sophisticated research continues.

The 2014 National Academies' report asserted that the research, development, and use of brain science in international military and security scenarios represent a significant and growing concern. In the United States and most Western nations, governmentally funded neuroscience programs adhere to dual-use research of concerns (DURC) policies, in keeping with the general constructs of the BTWC and CWC. But such control can also create a dilemma: It certainly creates parameters for the conduct of brain science in participatory states. Yet, at the same time, it can create opportunities for other nations or even non-state actors to take advantage of these constraints to gain a competitive edge toward attaining power. To be sure, international policies and treaties don't guarantee cooperation, and studies and applications of brain science need not be clandestine or covert. As previously noted, the current BTWC and CWC do not restrict pharmaceutical formulations of neurotropic drugs for medical use, or neurotechnologies (e.g., neurostimulatory or modulatory devices); exemptions for biomedical experimental purposes and/or shields of commercial proprietary interests and intellectual property can subvert inquiry into the dual-use or military applications of brain science.

Military Medicine: "Bench to Bedside" Applications

There is considerable literature addressing and describing evaluations and applications of neuroscientific tools' and techniques' capacity to sustain vigilance, increase coordination, improve memory and learning, decrease fatigue, and reduce stress. This has fostered steadily increasing interest in, desire for, and use of such approaches to affect performance in certain occupational settings. Additionally, there is growing interest in employing neuroS/T for educational as well as avocational/lifestyle (e.g., gaming; athletic) purposes. At present, most such applications are administered in supervised laboratory and/or clinical settings (inclusive of "off-label" medical uses), and are characteristically well-controlled and monitored, in that distinct regulations apply for off-label use in research and medical practice.

For example, in research settings involving human subjects, the use of any/all drugs and devices, any research must comply with the mandates of the Declaration of Helsinki, and must entail and obtain:

- Approval by an institutional review board (IRB) and, if the research engenders potential for serious risk to the health, safety, or welfare of a subject, approval of an investigational drug or device exemption (in the European Community by The European Medicines Agency)
- Informed consent from all patients
- Labelling of the drug and device for investigational use only
- Monitoring of the study and
- Requisite records and reports

Whereas in medical practice, the European Commission (EC) defines off-label uses as:

> *Situations where a medicinal product is intentionally used for a medical purpose not in accordance with the authorized product information. Off-label use includes use in non-authorized paediatric age categories. Unless specifically requested, it does not include use outside the EU in an indication authorized in that territory which is not authorized in the EU.*

This definition establishes that drugs and devices that have European marketing authorization will be eventually considered “off-label”; while those products without this authorization will be regarded as “unlicensed”. These definitions and existing regulations presume that any and all off-label use represents a matter of medical judgment and occurs in a conscientious manner with regard to good clinical practices.

Direct-to-Consumer Applications

An expanding industry that provides agents and devices directly to consumers (DTC) may warrant concern about public health and safety. In general, research supporting the development of neuroscientific drugs and devices that are made available to the DTC market is conducted either in academic laboratory settings, or directly by the commercial entity. In the former case, published studies of mechanisms and effects of neurotropic agents and devices may be simply utilized by a commercial entity for the development, substantiation, and/or marketing of their product(s). As well, some commercial entities will directly subsidize academic research to investigate putative mechanisms of and potential outcomes of a particular product, which is then used to advance claims of process and effect, safety, and value that can be leveraged for both regulatory approval and marketing. In the latter case, a commercial entity will conduct research in laboratory and/or restricted field settings using in-house resources and personnel.

In the EU (as in the United States), research and development (R&D) of these drugs and devices can be regarded as dual-use in that they are explicitly not intended to diagnose or treat a medical condition. Furthermore, the provision and use of these products are not supervised by a physician, and therefore, responsibility for appropriate use is shared, to some extent, by the commercial manufacturer and the consumer. To the extent that research studies are contributory to an understanding and explanation of these products' mechanisms, actions, and effects, there is also some degree of ethical (if not legal) enfranchisement of the participating researchers, although the nature and extent of these responsibilities remain a matter of discourse.

Here, key issues center upon if, and to what extent studies of mechanisms and effects are directly focal to a specific product, or represent mere generalizations. As well, there are concerns about the translation of findings generated under controlled laboratory settings to variable uses-in-practice, provision of information (and/or lack thereof) regarding effects, possible side- and adverse effects; and thorough definition and description of protocols for use. In the EU, product claims are overseen by both the European Trade Commission and national agencies within member countries. While these bodies define criteria for product labelling, there have been calls for an increased level of conformity in standards for research, marketing, and labelling of neuroscientific agents and devices that are offered DTC.

Do-it-Yourself/Neurobiohacking

There is also a growing do-it-yourself (DIY)/ biohacking community that is dedicated to modifying commercially available DTC products to perform different functions, and/or creating new products capable of affecting neurobiological functions. Biohacking typically implies modifications for benevolent ends (i.e., "white-hat" hacking), inclusive of development of agents and devices to improve human cognition, emotion, and behavioral performance. However, there is also a "black-hat" hacking community that engages DIY approaches to modifying neurobiology to produce pathogens, or to incur other disruptions in individual or community stability and safety. Biohacking can be articulated in three research domains: synthetic biology (e.g., genetic and molecular editing); biotechnology (human-machine interfaces, technological implants, and prosthetics); and biochemistry (e.g., development of neurotropic agents that can be used either singularly or in chemical cocktails). These categories and their products are not mutually exclusive.

DIY scientists/biohackers often work in coordination within an informally organized community, and much of their research is made publicly available through open access databases and websites of community laboratories. The spirit of the DIY/biohacking community reflects a movement to make biology "easier to engineer", and more publicly accessible and available. In part, this is constituent to an expanding trend toward "open source" biology that has influenced both research institutions and the public. Additionally, "open source" biology has captured an economic market niche: engineered and modified organisms, drugs, and devices can be sold; community laboratories can be purchased (by conventional commercial entities); and both community laboratories and individual DIY biohackers can be subsidized through venture capital. With manuals and methods available online, it is relatively easy to establish and run a laboratory, and interested individuals and groups can obtain guidance on producing and/or manipulating a variety of neurobiological techniques and technologies.

These same opportunities also pose potential regulatory, health, and security risks. Independent laboratories and researchers do not always abide by the comprehensive policies that academic and industrial research entities must follow. As well, there is increasing use of the "dark web" (covertly accessed Internet) by both "white-hat" and "black-hat" biohackers to facilitate exchange of information in ways that impede surveillance.

This community presents particular dual-use research concerns in that:

1. outcomes and products may be used or misused in ways that adversely impact individual and public health and safety, as well as the integrity of flora and fauna in the environment;
2. limitations and/or lassitude in research practices and/or laboratory conditions may incur accidental release of information or products that can pose health and environmental risks and harms; and/or
3. activities may be subsidized and outcomes and products utilized by national and non-state venture capitalists with explicit intent toward disrupting public safety, stability, and health.

These possibilities evoke security concerns on local, national, and international scales, and have warranted involvement of crime prevention and public safety agencies (e.g., the United States Federal Bureau of Investigation) to establish dialogue with, and insight to the DIY biohacking community. What is important to note is that neuroscientific and neurotechnological research and development is occurring on a variety of levels (from large scale academic and industrial laboratories to individual DIY experimenters) and is international. In this latter regard, it has been estimated that a significant and growing percentage of neuroscientific and technical research and development will be engaged outside of the West by 2025. This increases the possibility for dual-use research and DURC, and generates questions about what constitutes research for security purposes (i.e., preparatory defense) versus military/warfare (i.e., offensive capability) purposes.

Intelligence, Training and Operational Applications[5,6]

Research in cognitive and computational neuroscience is being engaged to improve:

- **Human cognitive performance** – through improved understanding of basic processes involved in memory, emotion, and reasoning to support and enhance intelligence analysis, planning, and forecasting capabilities.
- **Training efficiency –** by using knowledge and tools of cognitive neuroscience to enable more rapid acquisition and mastery of knowledge and skills with more durable retention.
- **Team process performance** – via engagement of systems engineering of human/brain interfacing to enhance information processing capability of individuals, organizations, and surveillance and weapons' systems (drones). Research in this domain generally employs a technology readiness/technology transfer approach that utilizes a nine-level assessment and articulation scheme (from observation of basic principles, through evaluation and validation in a relevant environment, to full operational readiness) to advance research, development, testing, and evaluation, toward rapid use. At present, a number of human/brain-machine interfaces are transitioning from development through test and evaluation stages toward operational readiness within a five-year cycle.

Neurocognitive studies employing various forms of neuroimaging, neurogenomics, proteomics, and biomarker assessment are being used to identify and define neural networks involved in several dimensions of operational performance of military combat and support personnel. These approaches seek to identify and isolate neural structures, systems, and functions that can be "targeted" for interventions utilizing non-invasive brain

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[5] Giordano J, Wurzman R. (2014). Validity, viability and value of neuro-cognitive science and technology in operational intelligence and deterrence. In: Cabayan H, Canna S. (eds.) *Multimethod Assessment of ISIL.* p. 87-94. Department of Defense; Strategic Multilayer Assessment Group- Joint Staff/J-3/Pentagon Strategic Studies Group.

[6] DeFranco JP, DiEuliis D, Giordano J. (2019). Redefining neuroweapons: Emerging capabilities in neuroscience and neurotechnology. *PRISM* 8(3): 48-63.

stimulation, pharmacological agents (e.g., stimulants, eugeroics; nootropics), or cognitive-behavioral training to facilitate, sustain, and/or improve performance capability and reduce dysfunction. An overview of these approaches is provided by Table 2.

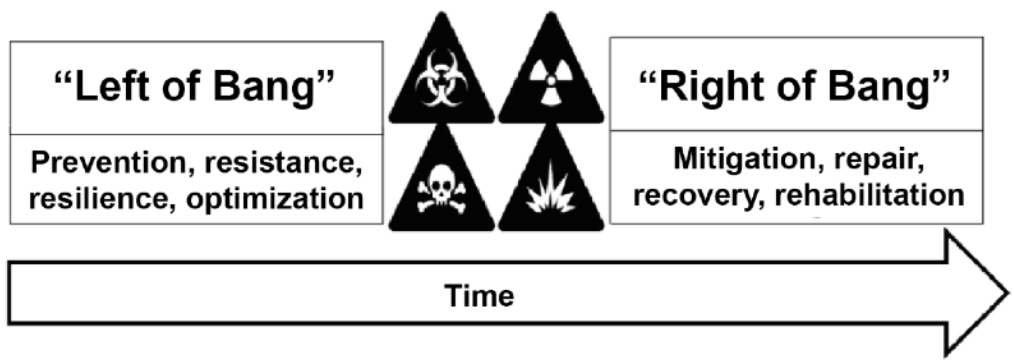
Table 2. NeuroS/T Approaches to Personnel Performance Optimization

Pharmacologic Agents	Types	Effects
Stimulants	Amphetamines (e.g., dextroamphetamine)	Facilitated attention, focus, and arousal; decreased fatigue; improved memory.
	Substituted phenylethylamines (e.g., methylphenidate)	
Eugeroics	modafinil; armodafinil	Increased wakefulness; decreased fatigue; facilitated reasoning.
Racetams	piracetam, oxiracetam, aniracetam	Putative general “nootropic” effects; increased focus.
Neurotechnologic Methods	**Types**	**Effects**
Neurofeedback	• EEG-based • Neuroimaging-based	Increased vigilance; directed attentiveness; improved concentration
Transcranial Neuromodulation	• tES • TMS	Improved vigilance; increased focus; improved cognitive reaction time.
Brain-Computer Interfacing (BCI)	EEG-based	Facilitated signal-noise/object recognition and discrimination

Abbreviations: EEG = electroencephalography; tES = transcranial electrical stimulation (e.g., direct, alternating and/or pulsed current stimulation); TMS = transcranial magnetic stimulation.

These assessments and interventions have been, and could be regarded as components of preventive military medicine (i.e., to be used “left of bang”, where “bang” is regarded as any inciting event; see Figure 1). Moreover, studies conducted within, and/or directly funded by the military have been utilized for their “reverse dual-use” applications in civilian occupational and preventive medical contexts. However, these techniques and technologies also raise concerns about creating "super soldiers" and intelligence operators (i.e., "super spooks") that obtain fortified cognitive, emotional, and behavioral characteristics that maximize their combat capabilities. A contrary position posits that such methods could, and arguably should be engaged to instead produce soldiers who possess improved decision-making, interpersonal, and perhaps even empathic characteristics and skills. These contrasting views fuel current discussion and debate.

Figure 1



Direct Weaponization of NeuroS/T [7,8,9]

The formal definition of a weapon as "a means of contending against others" can be extended to include any implement "…used to injure, defeat, or destroy". Both definitions apply to products of neuroS/T research that can be employed in military/warfare scenarios. The objectives for neuroweapons in a traditional military/warfare context (e.g., combat) may be achieved by augmenting or degrading functions of the nervous system, so as to affect cognitive,

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7 Wurzman R, Giordano J. (2015). NEURINT and neuroweapons: Neurotechnologies in national intelligence and defense. In: Giordano J. [ed.] *Neurotechnology in National Security and Defense: Practical Considerations, Neuroethical Concerns.* Boca Raton: CRC Press, pp. 79-114.

8 Giordano J. (2017.) Battlescape brain: Engaging neuroscience in defense operations. *HDIAC Journal* 3:4: 13-16 (2017).

9 DeFranco JP, DiEuliis D, Giordano J. (2019). Redefining neuroweapons: Emerging capabilities in neuroscience and neurotechnology. *PRISM* 8(3): 48-63.

emotional and/or motor activity and capability (e.g., perception, judgment, morale, pain tolerance, or physical abilities and stamina) necessary for combat. Many technologies (e.g., neurotropic drugs; neurostimulatory devices) can be employed to produce these effects, and there is demonstrated utility for neuroweapons in both conventional and irregular warfare scenarios.

The weaponized use of neuroscientific tools and products is not new. Historically, such weapons have included nerve gas and various drugs. Weaponized gas has taken several forms: lachrymatory agents (aka. tear gases), toxic irritants (e.g., phosgene, chlorine), vesicants (blistering agents; e.g., mustard gas), and paralytics (e.g., sarin). Pharmacologic stimulants (e.g., amphetamines) and various ergogenics (e.g., anabolic steroids) have been used to augment performance of combatants; and sedatives (e.g., barbiturates) have been employed to enhance cooperation during interrogation. Sensory stimuli (e.g., high intensity sound; prolonged flashing lights; irritating music or noise) have been applied as neuroweapons to incapacitate the enemy, and even sleep deprivation and distribution of emotionally provocative information in psychological operations (i.e., PSYOPS) could rightly be regarded as forms of weaponized applications of neuroscientific and neurocognitive research. The 2013 conflict in Syria involving the use of nerve gas, and the use of the neuroactive agent VX to assassinate Kim Jong-nam, estranged half-brother of North Korean leader Kim Jong-un demonstrate the ongoing relevance of nervous system targets.

At present, outcomes and products of computational neuroscience and neuropharmacologic research could be used for more indirect applications, such as enabling human efforts by simulating, interacting with, and optimizing brain functions, and the classification and detection of human cognitive, emotional, and motivational states to augment intelligence or counter-intelligence tactics. Human/brain-machine interfacing neurotechnologies capable of optimizing data assimilation and interpretation systems by mediating access to – and manipulation of – signal detection, processing, and/or integration are being explored for their potential to de-limit "human weak links" in the intelligence chain.

Additionally, there is interest in employing neurotechnology to augment the role, capability, and effects of PSYOPS in military and political missions. Programs such as *Sociocultural Content in Language* (SCIL) and the *Metaphor* program at IARPA were directed toward improving insight to cultural linguistic and emotional norms; and DARPA's *Narrative Networks* entailed a neurocognitive approach to understanding and modelling narratives in socio-cultural contexts. As noted in several SMA Group reports to the Pentagon, the intent and desired outcomes of this research is an improved understanding of neural bases and effects of narratives that can afford insights to influences and processes that affect brain development, function, and behavior, which can be operationalized to mitigate violence on a variety of scales.

Furthermore, neuropharmacologic, neurotoxicologic, neuromicrobiologic, and neurotechnologic research that has potential to develop non-lethal or lethal weapons in combat-related and/or special operations' deterrence operations. Weaponizable products of neuroscientific and neurotechnological research can be utilized to affect 1) memory, learning, and cognitive speed; 2) wake-sleep cycles, fatigue and alertness; 3) impulse control; 4) mood, anxiety, and self-perception; 5) decision-making; 6) trust and empathy; and 7) movement and performance (e.g., speed, strength, stamina, motor learning, etc.). In military/warfare settings, modifying these functions can be employed to mitigate aggression and foster cognitions and emotions of affiliation or passivity; induce morbidity, disability or suffering; and "neutralize" potential opponents or incur mortality.

As summarized by Table 3, non-lethal and lethal neuroweapons include various categories and classes of psycho-neuroactive drugs, a variety of microbial agents (e.g., bacterial and viral strains) that act directly or exert effect upon the central and/or peripheral nervous system; organic toxins; and neurotechnological devices (e.g., sensory and brain stimulation approaches) and products (e.g., nanotechnologically derived substances). Additionally, brain-machine interfacing and neural network-derived computational decision systems could be employed to develop remote control or autonomous/semi-autonomous capability for unmanned aerial, ground, and marine (surface and subsurface) vehicles that could function as weapon platforms. The use of unmanned vehicles as weapons is not novel, and the realization of fully autonomous capability is iterative. Such progression and integration of neurotechnologically-enabled capabilities render these weapons increasingly viable, and therefore a source of trepidation about near-term future developments that could be generated from ongoing research in neural architectures and human-machine systems.

Table 3. Weaponizable NeuroS/T

Pharmacologic Agents	
Tranquilizing agents	benzodiazepines; barbiturates; neuroleptics; etc.
Mood altering agents	monoamine agonists and re-uptake blockers
Affiliative agents	methylenedioxymethamphetamine-MDMA; oxytocin
Dissociative agents	ketamine; phencyclidine
Psychedelics/Hallucinogens	lysergic acid diethylamide; tryptamine derivatives; psilocybin
Cholinergic agents	pilocarpine; physostigmine; (RS)-propan-2-yl-methylphosphonofluoridate (sarin)
Microbial Agents	
Viruses	*Togaviridae:* Equine encephalitis; *Flaviviridae*: flavivirus
Bacteria	*Bacillis anthracis*: anthrax; *Clostridium botulinum*: botulism; cyanobacteria; *Gambierdiscus toxicus*: cinguatoxin
Organic Toxins	
Bungarotoxins	krait snake toxin
Conotoxins	cone snail toxins
Dendrotoxins	mamba toxin
Maculotoxin	Blue-ringed octopus symbiotic bacteriotoxin
Naja toxins	cobra toxins
Saxitoxin	shellfish toxin
Tetrodotoxin	pufferfish toxin
Neurotechnologies	
Neurosensory immobilizing devices	High output sensory stimulators (to evoke disorientation/ discomfort)
Transcranial neuromodulating devices	Neural network stimulators for use in in-close operations against individual actors/targets
Nano-neuroparticulates	High CNS aggregation lead/carbon-silicate nanofibers (CNS network disrupters)
	Neurovascular hemorrhagic agents (for in-close and population targeted use)
Neurodata	See below

Neurodata [10,11,12]

The combination of multiple disciplines (e.g., the physical, social, and computational sciences), and intentional "technique and technology sharing" have been critical to rapid and numerous discoveries and developments in the brain sciences. This process, advanced integrative scientific convergence (AISC), can be seen as a paradigm for de-siloing disciplines toward fostering innovative use of diverse and complementary knowledge-, skill-, and tool-sets to both de-limit existing approaches to problem resolution; and to develop novel means of exploring and furthering the boundaries of understanding and capability. Essential to the AISC approach in neuroscience is the use of computational (i.e., big data) methods and advancements to enable deepened insight and more sophisticated intervention to the structure and function(s) of the brain, and by extension, human cognition, emotion, and behavior.

Such capacities in both computational and brain sciences have implications for biosecurity and defense initiatives. Several neurotechnologies can be employed kinetically (i.e., providing means to injure, defeat, or destroy adversaries) or non-kinetically (i.e., providing "means of contending against others," especially in disruptive ways) engagements. While many types of weaponizable neuroS/T (e.g., chemicals, biological agents, and toxins) have been addressed in and by extant forums, treaties, conventions, and laws, other newer techniques and technologies – inclusive of neurodata – have not. In this context, the term "neurodata" refers to the accumulation of large volumes of information; handling of large scale and often diverse informational sets; and new methods of data visualization, assimilation, comparison, syntheses, and analyses. Such information can be used to (1) more finely elucidate the structure and function of human brain; and (2) develop data repositories that can serve as descriptive or predictive metrics for neuropsychiatric disorders.

However, the rapidity of such advances can – and often does – outpace securitization, and the uniquity of brain science and its applications – and meanings – render particular security vulnerabilities. Namely, the fact that the brain is regarded as the "source of the mind", and all of the functions and implications arising therein, establish a normative aspect to neurodata.

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[10] Giordano J. (2014). Intersections of "big data", neuroscience and national security: Technical issues and derivative concerns. In: Cabayan H et al. (eds.) *A New Information Paradigm? From Genes to "Big Data", and Instagrams to Persistent Surveillance: Implications for National Security*, p. 46-48. Department of Defense; Strategic Multilayer Assessment Group- Joint Staff/J-3/Pentagon Strategic Studies Group.

[11] DiEuliis D, Giordano, J (2016). Neurotechnological convergence and "big data": A force-multiplier toward advancing neuroscience. In: Collmann J, Matei SA (eds.) *Ethical Reasoning in Big Data*: *An Exploratory Analysis.* NY: Springer (2016).

[12] DiEuliis D, Lutes CD, Giordano J. (2018). Biodata risks and synthetic biology: A critical juncture. *J Bioterrorism Biodef* 9(1): 2-14.

Simply put, neurodata can afford bases of what constitutes "normality" of brain structure, and functions (of thought, emotion, and behavior). Access to such information can enable insertion of data (e.g., in medical records; databases; registries; etc.) to alter the normative stature of targeted individuals (e.g., developing data profiles that depict them to have, be premorbid for, and/or predisposed to neurological and psychiatric conditions). Purloining and/or modifying such information could affect military and intelligence readiness, force conservation, and mission capability, and thus national security. Manipulation of both civilian and military neurodata would affect the type of medical care that is (or is not) provided, could influence the ways that individuals are socially regarded and treated, and in these ways disrupt public health and incur socio-economic change.

As well, neurodata can afford genotypic and phenotypic information that can be used to develop "precision pathogens" capable of selectively affecting specific targets (e.g., individuals, communities; domestic animals; livestock; etc.). Recent development in gene editing tools and techniques, such as CRISPR-Cas 9 (when employed with other, existing molecular biological methods) can facilitate both the modification of extant agents to be more viable, durable, and/or virulent; as well as the development of novel bacteria and viruses that have unique properties, specific affinities, and/or no known treatment. As the current COVID-19 pandemic has revealed, public – and institutional public health – responses to novel pathogens are highly variable at best, chaotic at worst, and indubitably costly (on many levels) in either case. To be sure, such extant gaps in public health and safety infrastructures and functions could be exploited by employing "precision pathologies" and an aggressive program of misinformation to incur disruptive effects on social, economic, political, and military scales that would threaten national stability and security.

Digital biosecurity – a term that describes the intersection of computational systems and biological information and how to effectively prevent or mitigate current and emerging risk arising at this intersection – becomes ever more important and required. The convergence of neurobiology and computational capabilities, while facilitating beneficial advances in brain research and its translational applications, creates a vulnerable strategic asset that will be sought by adversaries to advance their own goals for neuroscience. Hacking of biological data within the academic, industry, and the health care systems has already occurred – and neurodata are embedded within all of these domains.

Thus, it is likely that there will be more direct attempts at harnessing neurodata to gain leverageable informational, social, legal, and military capability and power advantage(s), as several countries that are currently strategically competitive with the U.S. and its allies invest heavily in both neuro- and cyber-scientific research programs and infrastructure. The growing fortitude of these states' quantitative and economic presence in these fields can – and is intended to – shift international leadership, hegemony, and influence ethical, technical, commercial and politico-military norms and standards of research and use. For example, Russian leadership has declared interest in the employment of "genetic passports" such that those in the military who display genetic indications of high cognitive performance can be directed to particular military tasks.

Therefore, an integrative approach to digital biosecurity is required that can effectively and efficiently address present and future challenges. The integration must occur in the domains and dimensions that are most relevant and crucial to surveillance, oversight and direction of neurocognitive, and other types of biodata. Such an approach would necessitate: (1) integrative scientific convergent paradigm; (2) at least a whole of government, if not whole of nations' dedication; and (3) a multi-national re-address to more effectively guide and govern the ways that neurodata – and other bioinformation – are, and can be used in both non-kinetic and kinetic engagements.

NeuroS/T Commercialization and Growth: Economic Hegemony/Global Power [13]

Neuro-data – coupled to and synergizing (other) advancements in neuroS/T have contributed to much growth in the neuro-bioeconomy. To be sure, as current assessments and predictions from the Neurotechnologies Industries Organization, and Organisation for Economic Cooperation and Development reveal, there is – and will continue to be – an evident and expanding market opportunity for neuroS/T development and production. In a 2016 analysis of data from 195 countries, the Global Burden of Diseases, Injuries, and Risk Factors Study Group (GBD) found that neurological disorders are the second leading cause of death worldwide (with approximately 9 million deaths; constituting 16.5% of global fatalities). Additionally, neurological disorders are the leading cause of disability, incurring approximately 276 million disability-adjusted life-years. Assessments by the GBD also illustrate the magnitude of neuropsychiatric illnesses, with current estimates that these disorders account for one-third of worldwide disabilities. A report by the *Lancet Commission* estimates that between 2010 and 2030, the fiscal productivity loss incurred by neuropsychiatric conditions could be as high as $16 trillion (USD). The increased prevalence of these diseases in an aging population is placing significant burdens on healthcare systems, and generating substantial expenses in economic and social welfare.

When considering recent demographic trends and continuity of aging populations, neurological disorders may likely have a more significant impact in the near future. Current estimates project that the global population of people over the age of 60 years will increase from 800 million

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13 DeFranco JP, Rhemann M, Giordano J. (2020). The emerging neurobioeconomy: Implications for national security. *Health Security* 18(4): 66-80.

today to 2 billion in 2050 (accounting for ~22% of the world population). This percentage is disproportionately greater in developed nations. For example, dementing disorders (i.e., pathologies that present with a progressive decline in memory, emotion, and executive behavior) currently affect 50 million people; and it is projected that 152 million people will be affected by 2050. These disorders are – and are predicted to remain – a primary focus of global brain science.

While the search for improved diagnostics, treatments, and potential prevention of neuropsychiatric disorders are principal drivers of brain research, there is a growing commercial interest in developing applications of neuroS/T in direct-to-consumer (DTC) healthcare, education, information and communication technology, law enforcement, and military markets. For example, in the past ten years, the number of patents for DTC neurotechnologies has more than doubled; and the worldwide market for neurotechnology products is forecasted to increase from $8.4 billion (USD) in 2018 to $13.3 billion in 2022. Moreover, in 2019, several neurotechnology startups disclosed annual funding ranging from $1 million - $50 million (e.g., Thync, Halo Neuroscience); to $50 million - $100 million (e.g., Dreem, Kernel), to $100+ million (e.g., NeuroPace, MindMaze). Such financial success can be demonstrated by the size and relative growth of the global deep brain stimulation device market, which is projected to reach $2.3 billion by 2025, increasing 16.1% in compound annual growth rate between 2019-2025.

Interactive developments in neuroS/T and computational biology have enabled the leveraging of neuropsychiatric data (i.e., "neurodata."). The convergence of diverse approaches and disciplines, including the physical, social, and computational sciences, and intentional "technique and technology sharing" have been crucial to the number and rapidity of recent advances in the brain sciences. Concerted efforts in neuroinformatics are producing new computational tools that can aggregate, organize, synthesize, and employ neurodata for uses in research, and varied applications, inclusive of clinical medicine, law, and national security and defense.

As shown in Table 1, several countries have initiated programs in brain research and innovation (see Table 1). These initiatives aim to: (1) advance understanding of substrates and mechanisms of neuropsychiatric disorders; (2) improve knowledge of processes of cognition, emotion, and behavior; and (3) augment the methods for studying, assessing, and affecting the brain and its functions. New research efforts incorporate best practices for interdisciplinary approaches that can utilize advances in computer science, robotics, and artificial intelligence to fortify the scope and pace of neuroscientific capabilities and products. Such research efforts are strong drivers of innovation and development, both by organizing larger research goals, and by shaping neuroS/T research to meet defined economic, public health, and security agendas.

In an attempt to coordinate goals and projects, the International Brain Initiative (IBI) was established in 2017 with specific intent toward "catalyzing and advancing ethical neuroscience research through international collaboration and knowledge sharing, by uniting diverse ambitions to expand scientific possibility, and disseminating discoveries for the benefit of humanity.” Current constituents of the IBI include Australia, Canada, China, the European Union, Japan, Korea, and the United States. While the intent is notable, it remains to be seen if, and to what extent (1) the IBI will operate in partnership with other, extant organizations (e.g., Organisation for Economic Cooperation and Development; Institute of Electrical and Electronics Engineers; World Health Organization; etc.) that are dedicated to similar, if not identical aims; and (2) the formation and addition of another group devoted to these purposes will facilitate these means and ends, or merely become an example of “too many cooks ruining the broth”.

Security Challenges of the Neuro-bioeconomy

The U.S. National Academies of Science, Engineering, and Medicine has called for the need for the U.S. and its allies to recognize dual obligations to the emerging bioeconomy. First, is a responsibility for prudent direction and oversight, as failure to promote progress in/by biological and technological industries could result in losing leadership of the international community. Meeting this obligation could include adequately funding research and development in key areas, implementing appropriate research oversight, and educating the research workforce. Second, is the need to protect the bioeconomy from deliberate adversarial acts that could impede biotechnological progress and allow other international individuals, groups, or countries to gain power advantage. Engaging this responsibility could entail developing more rigorous methods of proper handling and oversight of biologicals and/or technology, affording ample protection of biological data and digital infrastructures, and the development and implementation of (more effective, and globally relevant and responsive) intellectual property laws.

Additionally, it is important to note that although the U.S. National Academies of Science, Engineering, and Medicine report briefly mentioned recent developments in brain-controlled robotics and brain-machine interface (BMI), neuroS/T, writ large, was not a core aspect of their address. At present, the majority of countries do not yet identify the brain sciences as a principal economic focus. Of the 41 nations that pursued specific political strategies to expand and promote their bioeconomies in 2018, only 10[14] included neuroS/T research and development objectives. So, while there may be little doubt that neuropsychiatric disorders are a significant public health problem, brain research is relatively costly and the perceived return-

[14] The countries or multi-national organizations that include neuroscience, neurotechnology, and/or brain science objectives in their bioeconomy strategies are Australia, Brazil, China, France, The European Union, India, Japan, South Korea, Thailand, and the United States.

on-investment for those countries that do not have substantial neuro-epidemiological burdens may not be sufficient to justify pursuing dedicated neuroS/T initiatives. However, while *intra*national human capital and socio-political agendas of a given nation may not prompt investment and engagement in neuro-bioeconomics, the relative economic – and perhaps cultural and political – hegemony afforded by leveraging global neuroS/T (and overall biological) markets might prove influential to changing perspectives, postures, and participation. To be sure, due to the current lack of emphasis on brain science in national bioeconomic strategies, those countries that initiate policies and programs to invest in neuroS/T may achieve significant financial successes, economic power, and thereby direct future (ethical, technical, and legal) standards of research and use.

Rapid advances in brain science represent an emerging domain that state and non-state actors can leverage in warfare, intelligence, and national security (WINS) operations. While not all brain sciences engender security concerns, predominant authority and influence in global biomedical, bioengineering, wellness/lifestyle, and defense markets enable a considerable exercise of power. It is equally important to note that such power can be exercised both non-kinetic and kinetic operational domains, and several countries have identified neuroS/T as viable, of value, and of utility in their WINS programs. While extant treaties (e.g., the BTWC and CWC) and laws have addressed particular products of the brain sciences (e.g., chemicals, biological agents, and toxins), other forms of neuroS/T, (e.g., neurotechnologies and neuroinformatics) remain outside these conventions' foci, scope, and governance. Technology can influence, if not shape the norms and conduct of warfare, and the future battlefield will depend not only upon achieving "biological dominance", but achieving "mental/cognitive dominance" and "intelligence dominance" as well. It is, and will be ever more difficult to regulate and restrict WINS applications of neuroS/T without established standards and proper international oversight of research and potential use-in-practice.

Furthermore, several aspects of the brain sciences make them particularly problematic for the biosecurity community. First, the field has become increasingly interdisciplinary, and strives to integrate several sciences and technologies (e.g., biology, chemistry, psychology, physics, computational sciences) to address neuroscientific questions and forge innovative discoveries and interventions. For instance, state and non-state actors can use novel neurotechnologies (e.g., BMIs and transcranial neural stimulation devices), and advances in neuroinformatics (i.e., analyzing neuroscientific data to better assess, access, and affect the nervous system) for WINS applications. At present, the development and use of these devices are underregulated and not included in dual-use export safeguards, thus making effective oversight of potential dual-use research of concern (DURC) difficult. Second, these neurotechnologies are as yet underexplored for their augmentative and destructive capabilities and uses. In contrast to other conventional biological and chemical weapons (e.g., microbes, toxins, chemicals), devices that affect the nervous system are relatively new, and have only recently been engaged for their WINS potential. This combination of "blank slate" and "unknown ground" dimensions of neurotechnology creates difficulties in realistic biosecurity forecasting and preparedness.

For the last two decades, publications in the brain sciences have steadily increased. Yet, for the aforementioned reasons oversight remains a problem, as surveillance of potential WINS applications is complexified by persistent challenges in tracking and evaluating (any) neuroS/T research and product development. Thus, the potential for dual- or direct-use of neuroS/T for disruptive or destructive purposes becomes increasingly viable.

Moreover, much of neuroS/T is reliant upon, and force multiplied by computational approaches and the use of big data. It is important to note, however, the rapidity of advances in cybertechnology and data analytics often outpace securitization. The term "cyberbiosecurity" has been proposed to describe the intersection of computational systems, biological information, and the processes required to effectively mitigate, and/or prevent new and emerging risks and threats. NeuroS/T data could be used to acquire "neuro-profiles" of individuals whom nefarious actors could target through the development and use of "precision pathologies". Recent elucidation of the Chinese government's Overseas Key Individuals Database (OKIDB), which, via collaboration with a corporate entity, Shenzhen Zhenua Data Technology, has amassed data to afford "insights into foreign political, military, and diplomatic figures…containing information on more than 2 million people…and tens of thousands who hold prominent public positions…" that could be engaged by "Beijing's army of cyberhackers" (see below).[15,16]

Clearly, brain science has become a multi-national enterprise. And, as previously noted, although some nations have not committed investments and resources to escalate neuroS/T initiatives, others most certainly have, and with ardent intent. In this light, it is important to note that differing cultural and political values can affect the ethical codes that guide and govern the conduct of scientific research. In some cases, these differing ethical standards may create opportunistic windows that can expedite neuroS/T research and advance outcomes and products to ultimately affect global markets.

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[15] Grigg A. Chinese database tracks U.S. nuclear scientists. (2020). *Australian Financial Review*, September 17. Available online at: www.afr.com.

[16] Delbert C. (2020). A Chinese database is tracking American nuclear scientists and military officers. *Popular Mechanics*, October, 28; vol. 10. Available online at: www.popularmechanics.com.

Nation State Case Study 1: China[17,18]

As described in the Five-Year Plans (FYPs) and other national strategies, China has identified and acknowledged the technical, economic, medical, military, and political value of the brain sciences, and has initiated efforts to expand its current neuroS/T programs. China utilizes broader strategic planning horizons than other nations and attempts to combine efforts from government, academic, and commercial sectors (i.e., the "triple helix") to accomplish cooperation and centralization of national agendas. This coordination enables research projects and objectives to be used for a range of applications and outcomes (e.g., medical, social, military). As noted by Moo Ming Poo, director of China's Brain Project, China's growing aging population is contributing to an increasing incidence and prevalence of dementia and other neurological diseases. In their most recent FYP, China addressed economic and productivity concerns fostered by this aging population, with a call to develop medical approaches for neurological disorders and to expand research infrastructure in neuroS/T. This growing academic environment has been leveraged to attract and solicit multi-national collaboration. In this way, China is affecting international neuroS/T through (1) research tourism; (2) control of intellectual property; (3) medical tourism; and (4) influence in global scientific thought. While these strategies are not exclusive to neuroS/T; they may be more opportunistic in the brain sciences because the field is new, expanding rapidly, and its markets are growing, and being defined by both share- and stake-holder interests.

Research tourism involves strategically recruiting renowned, experienced scientists (mostly from Western countries), as well as junior scientists to contribute to and promote the growth, innovation, and prestige of Chinese scientific and technological enterprises. This is apparent by two primary efforts. First, initiatives such as the Thousand Talents Program (launched in 2008) and other programs (e.g., Hundred Person Program, Spring Light Program, Youth Thousand Talents Program, etc.) aim to attract foreign researchers, nurture and sustain domestic talent, and bring back Chinese scientists who have studied or worked abroad. Further, China's ethical research guidelines are, in some domains, somewhat more permissive than those in the West (e.g., unrestricted human and/or non-human primate experimentation), and the director of China's Brain Project, Mu-Ming Poo, has stated that this capability to engage research that may

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17 Chen C, Andriola J, Giordano J. (2018). Biotechnology, commercial veiling, and implications for strategic latency: The exemplar of neuroscience and neurotechnology research and development in China. In: Davis ZS, Nacht M. (eds.) *Strategic Latency: Red, White and Blue: Managing the National and International Security Consequences of Disruptive Technology*. Livermore CA: Lawrence Livermore Press, pp. 12-32.

18 Giordano J, Bremseth LR, DeFranco JP. (2019). *Dual- and non-kinetic use of Chinese brain science: Current activities and future implications.* In: Petersen N. (ed.) *Chinese Strategic Intentions: A Deep Dive into China's Worldwide Activities.* Department of Defense; Strategic Multilayer Assessment Group- Joint Staff/J-3/Pentagon Strategic Studies Group.

not be (ethically) viable elsewhere may (and should) explicitly attract international scientists to conduct research in China.

Second, China continues to engage with leading international brain research institutions to foster greater cooperation. These cooperative and collective research efforts enable China to achieve a more even "playing field" in the brain sciences. China leverages intellectual property (IP) policy and law to advance (and veil) neuroS/T and other biotechnologies in several ways. First, via exploitation of their patent process by creating a "patent thicket". The Chinese patent system focuses on the end-utility of a product (e.g., a specific neurological function in a device), rather than emphasizing the initial innovative idea in contrast to the U.S. system. This enables Chinese companies and/or institutions to copy or outrightly usurp foreign patents and products. Moreover, Chinese patent laws allow international research products and ideas to be used in China "for the benefit of public health," or for "a major technological advancement." Second, the aforementioned coordination of brain science institutions and the corporate sector establishes compulsory licensing under Chinese IP and patent laws. This strategy (i.e., "lawfare") allows Chinese academic and corporate enterprises to have economic and legal support, while reciprocally enabling China to direct national research agendas and directives through these international neuroS/T collaborations. China enforces its patent and IP rights worldwide, which can create market saturation of significant and innovative products, and could create international dependence upon Chinese neuroS/T. Further, Chinese companies have been heavily investing in knowledge industries, including artificial intelligence enterprises, and academic book and journal partnerships. For example, TenCent established a partnership with Springer Nature to engage in various educational products. This will allow a significant stake in future narratives and dissemination of scientific and technological discoveries.

Medical tourism is explicit or implicit attraction and solicitation of international individuals or groups to seek interventions that are either only available, or more affordable in a particular locale. Certainly, China has a presence in this market, and at present, available procedures range from the relatively sublime, such as using deep brain stimulation to treat drug addiction, to the seemingly "science-fictional", such as the recently proposed body-to-head transplant to be conducted at Harbin Medical University in collaboration with Italian neurosurgeon Sergio Canavero. China can advance and develop areas of neuroS/T in ways that other countries cannot or will not, through homogenizing a strong integrated "bench to bedside" capability and use of non-Western ethical guidelines.

China may specifically target treatments for diseases that may have a high global impact, and/or could offer procedures that are not available in other countries (for either socio-political or ethical reasons). Such medical tourism could create an international dependence on Chinese markets as individuals become reliant on products and services available only in China, in addition to those that are "made in China" for ubiquitous use elsewhere. China's growing biomedical industry, ongoing striving for innovation, and expanding manufacturing capabilities have positioned their pharmaceutical and technology companies to prominence in world markets. Such positioning – and the somewhat permissive ethics that enable particular aspects and types of experimentation – may be seductive to international scientists to engage research, and/or commercial biomedical production within China's sovereign borders.

Through these tactics of economic infiltration and saturation, China can create power hierarchies that induce strategically latent "bio-political" effects that influence real and perceived positional dominance of global markets.

China is not the only country that has differing ethical codes for governing research. Of note is that Russia has been, and continues to devote resources to neuroS/T, and while not uniformly allied with China, has developed projects and programs that enable the use of neurodata for non-kinetic and/or kinetic applications (see below). Such projects, programs, and operations can be conducted independently and/or collaboratively to exercise purchase over competitors and adversaries so as to achieve greater hegemony and power. Therefore, NATO, and its international allies must (1) recognize the reality of other countries' science and technological capabilities; (2) evaluate what current and near-term trends portend for global positions, influence, and power; and (3) decide how to address differing ethical and policy views on innovation, research, and product development.

Nation State Case Study 2: Russia[19]

Russian President Vladimir Putin has explicitly stated intent to implement an aggressive modernization plan via the National Technology Initiative (NTI). Designed to grant an overmatch advantage in both commercial and military domains against Russia's current and near-term future key competitors, the NTI has been viewed as somewhat hampered by the nation's legacy of government control, unchanging economic complexity, bureaucratic inefficiency and overall lack of transparency. However, there are apparent disparities between such assessment of the NTI and its capabilities, and Russia's continued invention and successful deployment of advanced technologies.

Unlike the overt claims and predictions made by China's scientific and political communities about the development and exercise of neuroS/T to re-balance global power, explication and demonstration(s) of Russian efforts in neuroS/T tend to be subtle, and detailed information about surveillance and extent of such enterprise and activity is, for the most part, restricted to

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19 Giordano J. (2017). Neuroscience and technology as weapons on the twenty-first century world stage. In: Aviles W, Canna S. (eds.) *Influence in an Age of Increasing Connectedness.* p. 58-66. Department of Defense; Strategic Multilayer Assessment Group- Joint Staff/J-3/Pentagon Strategic Studies Group.

the classified domain. In general, Russian endeavors in this space tend to build upon prior work conducted under the Soviet Union, and while not broad in focus, have gained relative sophistication and capability in particular areas that have high applicability in non-kinetic disruptive engagements. Russia's employments of weaponized information, and neurotropic agents have remained rather low-key, if not clandestine (and perhaps covert), often entail nation-state or non-state actors as proxies, and are veiled by a successful misinformation campaign to prevent accurate assessment of their existing and developing science and technologies.

Military science and technology efforts of the USSR were advanced and sustained primarily due to the extensive military-industrial complex which, by the mid-1970s through 1980s, is estimated to have employed up to twenty percent of the workforce. This enabled the USSR to become a world leader in science and technology, ranked by the U.S. research community as second in the world for clandestine S&T programs (only because the overall Soviet system of research and development (R&D) was exceptionally inefficient, even within the military sector). The collapse of the USSR ended the Soviet military-industrial complex, which resulted in significant decreases in overall spending and state support for R&D programs. Any newly implemented reforms of the post-Soviet state were relatively modest, generating suboptimal R&D results at best. During this time, Russian R&D declined by approximately 60% and aside from the Ministries' involvement with the military sector, there was a paucity of direct cooperation between Russian R&D institutions and operational S&T enterprises. This limited interaction, was further compounded by a lack of resources, inability to bring new technology to markets, absent protections for intellectual property, and "brain drain" exodus of talented researchers to nations with more modern, cutting-edged programs with better pay and opportunities for advancement.

Recognizing the inherent problems with the monoculture of the Russian economic and S&T ecosystems, the Putin government initiated a process of steering Russia toward more lucrative, high-tech enterprises. The NTI is ambitious, with goals to fully realize a series of S&T/R&D advancements by 2035. The central objective of the NTI is establish "the program for creation of fundamentally new markets and the creation of conditions for global technological leadership of Russia by 2035." To this end, NTI Experts and the Agency for Strategic Initiatives (ASI) identified nine emerging high-tech markets for prime focus and penetrance, including neuroscience and technology (i.e., what the ASI termed "NeuroNet"). Substantive investment in this market is aimed at overcoming the post-Soviet "resource curse", by capitalizing on the changes in global technology markets – and engagement sectors – to expand both economic and military/intelligence priorities and capabilities. According to the ASI, NeuroNet is focused upon "distributed artificial elements of consciousness and mentality", with Russia's prioritization of neuroS/T being a key factor operative in influence operations directed and global economies and power. Non-kinetic operations represent the most viable intersection and exercise of these commercial, military, and political priorities, capabilities, and foci of global influence and effect(s).

A Case Study in Corporate Commercialization: *Neuralink*[20]

In 2019, Elon Musk announced that his company, *Neuralink*, would advance the clinical translation of a novel BMI that he claims holds "…promise for the restoration of sensory and motor function and the treatment of neurological disorders." The BMI involves implantation of microelectrodes in the brain to record neurological activity, which then conveys signals to sensors that can be detected by an external device, such as a smartphone. Due to the complex nature of this procedure, *Neuralink* plans to develop a robotic system for implanting electrodes. This system will be monitored and managed by a neurosurgeon who can manually adjust the robotic system as needed during the procedure. Although the company's efforts to develop such a BMI have only been underway for little more than two years, it has already created an innovative, functioning application in an *in vivo* rat model. Musk seeks to begin clinical trials this year for treatments of certain neurological disorders, and he asserts that this technology could and should be available to any individual who wishes to achieve "better access" and "better connections" to "the world, each other, and ourselves."

Presentations by Musk have asserted that a primary goal is to make the procedure "… as simple and automated as LASIK." Yet, until the robotics, external devices, and neurosurgeons are available worldwide, there will only be a few places in the world that will be able to offer this intervention. Given current views of scientists in the United States, Europe, Japan, and Australia regarding medical interventions intended for "non-therapeutic" (i.e., optimization/ enhancement) purposes, it seems unlikely that surgeons would (want to) perform the *Neuralink*/BMI procedure.

If this is the case, questions arise as to where these procedures would be provided, and how this technology and interventions will be funded. As noted, some nations' cultural views, needs, values, philosophies, ethics, and politics may make them more inclined, if not eager to adopt – and support, nurture, and further – BMIs, and other forms of emerging neuroS/T, for use in healthcare, various occupations, the general population, and military and intelligence personnel. This then raises the specter of if – and to what extent – such enterprises could be

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[20] De Franco JP, Giordano J. (2020). Mapping the past, present, and future of brain research to navigate the directions, dangers, and discourses of dual-use. *EC Neurol* 12(1): 1-6.

viewed, solicited, and used to influence local and global bioeconomies, and the relative balance(s) of power yielded by position and prominence within these hierarchies.

In the coming years, it is likely that such neuroS/T will become more available, effective, and employed. Using and/or modifying neuroS/T, while requiring specific disciplinary expertise (e.g., bioengineering, neurosurgery, computational neuroscience, etc.), will not pose excessive difficulty, given that several nations:

1. already have neuroS/T programs that are – and could be – devoted to military and intelligence efforts;
2. have relatively seamless integration of governmental, research/academic, and industrial sectors' "triple helix") that facilitate rapid throughput of S&T R&D for economic and military/intelligence agendas that could be engaged in non-kinetic and/or kinetic operations; and
3. have differing cultural values and ethical norms and mores may enable more rapid research timelines, and broader translation and use in these ways.

Recommendations

In sum, it is not a question of whether neuroS/T will be utilized in military, intelligence, and political operations, but rather when, how, to what extent, and perhaps most importantly, if NATO and its allies will be prepared to address, meet, counter, or prevent these risks and threats. In this light (and based upon the information presented in this report) it is, and will be increasingly important to address the complex issues generated by the brain sciences' influence upon global biosecurity and the near-term future scope and conduct of both non-kinetic and kinetic military and intelligence operations. [21]

Thus, if NATO countries – and their international allies – seek to retain a leading role in the global balance(s) of power, it will be essential to establish and sustain an iterative stake in the funding, guidance, and oversight of brain sciences in national security, intelligence, and defense operations. This is particular important given the recent opinion statement and recommendation(s) of the Task-Force on Dual-Use Neuroscience of the European Union Human Brain Project (EU-HBP),[22] which advocated that any/all R&D projects, outcomes, techniques, and tools conducted under the auspices and support of the HBP not be utilized

[21] DeFranco JP, DiEuliis D, Bremseth LR, Snow JJ. Giordano J. (2019). Emerging technologies for disruptive effects in non-kinetic engagements. *HDIAC Currents* 6(2): 49-54.

[22] Evers K, Farisco M, Giordano J, Salles A. (2017). *Dual Use in Neuroscientific and Neurotechnological Research. A Report on Background, Developments and Recommendations for Ethical Address, Assessment and Guidance of Human Brain Project Activities*. European Union Human Brain Project Report.

in/for military and/or intelligence (or other forms of security and defense) initiatives or operations. While noteworthy for its pacifist stance and advocacy, the unavailability of these state-of-the-art developments to the NATO mission (and the publication/dissemination of these studies and methods in the international scientific literature) essentially create an opportunity for competing nations to usurp and exploit such developments for use in their own military, intelligence, and political programs, projects and operations.

Therefore, the following steps are recommended:

- Recognition that brain science can and will be developed and used for non-kinetic and kinetic WINS engagements.
- Acknowledgement that other countries may employ different ethical systems to govern neuroscientific research and development. This will mandate a rigorous, more granular, and dialectical approach to negotiate and resolve issues and domains of ethical dissonance in multi- and international biosecurity discourses.
- Ongoing review and evaluation of national intellectual property laws, both in relation to international law(s), and in scrutiny of potential commercial veiling of dual-use enterprises.
- Ongoing surveillance of international activities in brain science, and their dual- and direct-use in military and intelligence operations.
- Identification and quantification of current and near-term risks and threats posed by such enterprise(s)
- Assessment of extant capabilities and gaps in NATO infrastructure and function(s) relevant to maintaining a stance of biosecurity preparedness, readiness, and response.
- Proactive bridging or de-limiting of gaps in biosecurity infrastructure and function so as to establish and sustain readily active resources, mechanisms, and policies to mitigate existing and near-term threats.
- Dedication of resources for developing and sustaining NATO (and allied nations') capabilities to prevent escalation of future risk and threat by (1) continued surveillance; (2) organizational and systemic preparedness; (3) conjoinment of any/all entities necessary to remain apace with, and/or ahead of tactical and strategic competitors' and adversary's capabilities in this space.
- A NATO program (or network of programs) to:
    - coordinate governmental, academic, and industrial sectors to study and evaluate current and near-future risks and threats;
    - establish (titular NATO) institutes/centers specifically dedicated to these pursuits, so as to obviate burden of participation/responsibility from any/all academic and other scientific institutions that are operating within/under EU-

HBP guidelines proscribing dual- or direct-use/involvement with military/ defense initiatives;
    - defend NATO countries and allied interests from these threats; and
    - develop methods to exploit competitors' gaps and weaknesses in these domains so as to maintain a favorable balance of power (in and across socio-economic, political, and military domains) in global engagements.
- Development and coordination of a *whole of (NATO) nations* (versus merely whole of governments or militaries) approach to mobilize the organizations, resources, and personnel required to meet global competitors and potential adversaries' synergistic triple helix capabilities for advancing neuroS/T that is viable and valuable in military and intelligence operations.