# A Brief Primer on the Concept of the Neuroweapon for U.S. Military Medical Personnel

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## ABSTRACT

The malevolent application of neuroscience is an emerging threat to the U.S. military. At present, U.S. military medical personnel are not capable of adequately diagnosing or treating the injuries and illnesses that may result from exposure to potential neuroweapons. This fact was illustrated in 2016 when U.S. diplomats serving in Havana, Cuba reported hearing strange noises accompanied by a constellation of unexplained health effects. Similar incidents have been reported in China and Russia. Although various hypotheses have been put forward to explain these symptoms, none of them have been verified. The reported symptoms were analogous to the physiological responses that have been produced in the laboratory by exposing volunteers to pulsed microwave energy. However, these incidents of undetermined origin demonstrate that widespread neurological illness can be disruptive to U.S. government operations and that it is currently not possible to identify the cause, determine the correct treatment, or ascribe attribution to potential neuroweapon use in an overseas setting. Since it is likely that Special Operations medical personnel will be among the first to respond to neuroweapon attacks in the deployed environment, it is essential that they be made aware of this emerging threat and that efforts be made to incorporate potential directed energy neuroweapons and other neuroweapon configurations into future Chemical, Biological, Radiological, Nuclear, and high yield Explosives (CBRN-E) training modules. The intention of this article is to introduce the concept of the neuroweapon to military medical personnel and to provide a brief review of the relevant literature.

KEYWORDS: *neuroweapon; neuroscience; Havana syndrome; microwave weapon; neurological injury*

## Introduction

The central nervous system is a complex information processing network. It collects and integrates information from the environment through the sense organs and uses this information to derive appropriate physical and physiological responses. During acts of cognition, internal mental representations of the physical world are constructed. These models are then used to evaluate the current physiological and environmental state, predict future states, and test possible responses.[1] It is well known that the stress of war can degrade the ability of the nervous system to acquire, process, and store information and that this degradation can be based on physical alterations in brain structure.[2] The fog of war and the cognitive overload resulting from the combat environment often make it difficult for military decision-makers to extract the relevant signals from the environment necessary to build reliable models used to derive appropriate responses during times of conflict.[3] In future peer and near-peer conflicts, the ability to master the cognitive domain and protect friendly forces from intentional attacks on their cognitive states might become essential factors in the winning or losing of individual battles and, by extension, in the winning or losing of a major war.[4,5]

Between 2016 and 2017, more than a dozen U.S. diplomats stationed in Havana, Cuba, began experiencing strange symptoms that included hearing chirping sounds, experiencing increased anxiety, and having disruptions in cognition.[6] Although the causes of these symptoms have not been identified, it has been speculated that they may have been the result of a directed energy attack on the human nervous system.[6,7] Similar symptoms have also been experienced by U.S. personnel stationed at the U.S. consulate in Guangzhou, China, and in Russia. These incidents have prompted a series of official investigations and have received the attention of scientific researchers in both academia and government.[8–10] A recently released intelligence assessment of Havana syndrome has indicated that there is a low probability of foreign adversary involvement.[11] This assessment was based in part on an apparent lack of detectable foreign adversary activity in the area during the incident, the inability to identify an adversary with a technology capable of causing the reported symptoms, and a lack of coherence among the symptoms as described by the victims. However, it is interesting to note that a previous intelligence assessment indicated that pulsed radiofrequency energy, sonic energy, or other forms of radiation were plausible proximate causes of the syndrome.[12] While future analyses may reveal the true cause of Havana syndrome, it is certain that the disruptive nature of these events is being monitored by state and non-state adversaries and that technologies currently exist that can mimic the symptoms of Havana syndrome.[13,14] In addition, there is historical precedent for foreign adversaries exposing U.S. personnel to directed energy pulses. From the late 1950s until the mid-1970s, the Soviet Union irradiated the U.S. embassy in Moscow with microwave radiation.[15] The motive behind this activity has never been identified, but it serves as an illustration that irradiation of embassy personnel is not beyond the ethical standards of some state actors. If these events are evaluated through the lens of the rapid advances in

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neuroscience that have occurred over the last 30 years, it may be found that they may signal a shift in the practice of modern warfare that goes beyond the realm of psychological operations and information dominance into the realm of focused attacks on the physical architecture of cognition itself. The term *neuroweapon* has been used to describe those technologies that are capable of degrading or modifying the human nervous system with the intent of affecting the cognitive, emotional, or motor function status of the enemy.[16] Neuroweapons may come in many forms and be delivered by a wide variety of systems. The human mind can be affected by neurochemical agents, biological agents, or directed energy (sonic energy and electromagnetic radiation).[8] Intriguingly, the concept of attacking the cognitive process in war is not a new one. As early as the fourth century B.C., the Chinese general, strategist, tactician, and military writer known as Sun Tzu stated, "To subdue the enemy without fighting is the acme of skill."[17] The application of recent advances in neuroscience, physics, and biological psychology to military tactics, operations, and strategy might lead to a future in which winning cognitive wars and neurological battles may be just as important as conventional kinetic confrontation. It may also lead to a future in which the nervous system is seen as a center of gravity and a primary object of direct attack. Consequently, U.S. military medical personnel need to be prepared to deal with the casualties of both current and future neurological weapons and be capable of developing methods to prevent, identify, and mitigate the impact of their use on military operations.

## Biological Neuroweapons

Cognition is a direct result of the underlying physical architect of the brain.[18] Eons of predator and prey interaction have driven the evolution of bacterial, viral, and fungal pathogens to the point that they can alter the underlying structures of the nervous system.[19] Numerous studies have identified a positive association between perinatal infection with specific viruses, bacteria, and fungi and the development of cognitive lesions, such as schizophrenia and bipolar disorder.[20] Indeed, in the years immediately following the conclusion of the 1918 Influenza Pandemic, cases of Parkinson's disease and other neurological disorders were reported to have increased.[21] These phenomena may have been linked to instances of virus-induced damage to the brain, as current research indicates that influenza infection in experimental animals can lead to neurological lesions, behavioral changes, and structural alterations.[21] In addition, SARS-CoV-2, the causative agent of COVID-19, has been shown to be a neurotropic virus.[22] Infection with it has been positively associated with the development of neurological symptoms and the subsequent formation of various cognitive impairments. [23] It remains to be seen whether there will be any long-term neurological consequences from the COVID-19 pandemic and whether this agent can be used for offensive purposes. However, it is possible that the intentional distribution of similar neurotropic viruses can be used as neuroweapons. Therefore, the neurological effects of viral pathogens should be closely monitored and evaluated for weaponization potential. In addition, efforts should be undertaken to characterize, diagnose, and treat the effects of these agents.

Parasites collectively form the most well-known and the most extensively studied group of organisms that have been found capable of altering human cognition. The alveolate, *Toxoplasma gondii* is a eukaryotic parasite that is typically transmitted in an enzootic cycle between various feline species and several types of rodents. It is believed that *T. gondii* evolved the ability to alter the behavior of its mammalian hosts as a way of self-preservation.[24] This parasite inhibits the normal fear response of host rodents, allowing them to be more easily captured and ingested by cats.[25] Such activity enables the parasite to quickly and efficiently move from host to host. Interestingly, human studies have demonstrated that there is an increase in the risk-taking behavior of humans who become infected with *T. gondii*. [25] The intentional inoculation of military personnel or civilian policy and decision-makers with this agent might increase risk-taking behavior to a level that leads to incorrect calculations and faulty maneuvers. These deficits might be exploited by an adversary and give them an unexpected competitive advantage.

Throughout evolution, the human nervous system has been the target of the toxic chemical byproducts of both terrestrial and marine organisms. These neurotoxins include saxitoxin, tetrodotoxin, conotoxin, bungarotoxin, tetanus toxin, taipoxin, and botulinum toxin. At least six countries (Japan, the UK, U.S., Germany, USSR, and Iraq) are known to have conducted research operations into the development of biological neurotoxin-based weapons.[26] Among these, botulinum toxin has the greatest number of unique properties conducive to weaponizing. First documented as a food-borne pathogen in the late 1700s, botulinum toxin refers to a group of proteins produced by the bacterium *Clostridium botulinum* and related species. It acts on the peripheral nervous system by blocking the release of the neurotransmitter acetylcholine at the neuromuscular junction, resulting in symmetrical flaccid paralysis that progresses over hours to days without fever or altered sensorium.[27] In addition, botulinum toxin can gain access to the central nervous system and alter brain function.[28] It is worth noting that the symptom severity of this agent is directly related to dose, and therefore the effects can possibly be tailored for specific purposes by an adversary. It has been found that as little as 0.7–0.9μg of botulinum toxin can be lethal if it is acquired through the inhalational route.[29] Case confirmation can be time-consuming and is typically done by detection of the toxin itself or by identification of the causative organism by culture, but this approach may take more than 24 hours.[30,31] To treat casualties resulting from this potential neuroweapon, a high index of suspicion will be needed, and prompt initiation of antitoxin treatment and supportive care will be required.[30] Thus, military medical personnel will need to be aware of the potential for the deployment of this agent and have the necessary supplies and reagents ready and available.

It is important to note that both the *C. botulinum* bacteria and the purified toxin can be aerosolized. Consequently, they were studied as potential bioweapons at Fort Detrick during World War II.[31] A variety of non-state actors have also studied and developed botulinum toxin as a weapon. It was implicated (but not confirmed) in the assassination of Reinhard Heydrich, the acting reich-protector of Bohemia and Moravia in May 1942, and it is suspected to have been prepared for use by the West-German terrorist group Red Army Faction in 1980.[32] This agent was also used by the Japanese cult Aum Shinrikyo during the 1990s in multiple terrorist attempts that fortunately did not result in any casualties, as the plans were foiled because of a failure to correctly isolate the strains of *C. botulinum* that produce toxin.[33] These cases indicate that, while the bacteria may be easy to acquire, weapon production

requires a level of expertise that might not always be available to non-state actors.

## Chemical Neuroweapons

Careful observation of the natural world led to the discovery of abiotic toxic compounds. These agents were applied to hunting and warfare as early as the Paleolithic era (approximately 12,000 years ago).[34] Early hunters took advantage of the neurotoxic effects of plant alkaloids, such as strychnine (spastic convulsant), aconitine, toxiferine I (paralytic), and tubocurarine to increase the effectiveness of their arrows and spears in Europe, Asia, and South America. These compounds would eventually be found with plant alkaloids in the battle for Kirrha during the First Sacred War in the sixth century B.C. They were also used by the Scottish who poisoned the invading Norwegian army's food in the 11th century and in the development of toxin-filled grenades, specialized toxin-filled ammunition in small arms, and the production of toxin-containing bombs during the industrial era.[34]

The chemical revolution of the 19th century opened the door to the development of synthetic neurotoxins that could be produced at industrial scales and applied to modern warfare. For example, the organophosphate tabun was noted to be extremely toxic to humans, and, although it was initially developed as an industrial insecticide, it was manufactured as a neuroweapon and used during the Iran-Iraq War.[35] Exposure to this agent resulted in increased acetylcholine circulation and global activation of neurons, leading to the classic toxidrome of excessive secretions, respiratory distress, and paralysis that is now described with the acronym DUMBELS (defecation, urination, muscle weakness, miosis, bradycardia, bronchospasm, bronchorrhea, emesis, lacrimation, and salivation).[36] Similar agents were quickly identified, and these led to the development and production of the G series of nerve agents tabun (GA), sarin (GB), chlorosarin (GC), soman (GD), ethylsarin (GE), and cyclosarin (GF) for military use during World War II (WWII).[37] After WWII, further research into nerve agents produced the V series of agents (of which VX is most well-known), novichok, and the carbamate nerve agents.[38]

Tabun, sarin, soman, cyclosarin, and VX are the most toxic nerve agents that have been developed to date and are the most likely agents to be employed in combat.[39] However, the only battlefield use of nerve agents occurred during the Iran-Iraq War when Iraqi forces are suspected to have exposed the village of Halabja to chemical agents, which may have included neurotropic compounds.[40,41] Historically, nerve agents have been used by state and non-state actors during terrorist acts or in assassination attempts. For example, sarin was used in multiple terrorist attacks by the Japanese doomsday cult known as Aum Shinrikyo in the 1990s, VX gas was reported to have been used by North Korean agents in the assassination of Kim Jong-Nam in 2017, and novichok was used in the poisoning of Sergei and Yulia Skripal by the Russian government in 2018.[42–46]

Treatment of nerve agent exposure consists of decontamination, ventilation, supportive care, and antidote therapy (atropine, pralidoxime, and diazepam).[47] Early recognition and treatment are critical owing to time-based properties that have been observed with several nerve agents. Namely, antidotes can become ineffective after the nerve agent and target protein become tightly fastened and a change in the structure of the protein complex occurs. This process is known as aging and is an important factor in determining the correct course of treatment for nerve agent exposure.[48]

An incapacitating agent known as BZ was developed and weaponized by the U.S. government during the Cold War.[49] BZ is a powerful anticholinergic that produces a toxidrome of delirium, vasodilation, xerostomia, hyperthermia, and mydriasis.[50] Exposure to BZ results in incapacitating altered mental states, including cognitive dysfunction, hallucinations, and the inability to perform basic tasks. It was weaponized by the U.S. Army as an aerosolized incapacitating agent. A similar anticholinergic agent has been allegedly developed and weaponized by the governments of Iraq and Syria. Deployment of this agent or similar agents in future conflicts remains a possibility and should be prepared for.

## Directed Energy Neuroweapons

While it is well known that ionizing radiation such as gamma rays and X-rays have sufficient energy to break chemical bonds and damage DNA, exposure to non-ionizing forms of radiation can also have biological effects.[51] However, this type of energy primarily tends to cause injury through thermal excitation mechanisms and subtle interactions with cellular biochemistry.[52] Safety limits on exposure times and doses have been established by government agencies mainly to protect against the possibility of unintentional tissue heating.[53] Exposure to non-ionizing radiation within safety limits is widely considered to be safe. However, numerous studies have shown that auditory, behavioral, and physiological responses can result from exposure to specific frequencies and wavelengths.[54,55] Recent studies on pulsed radiofrequency effects on the nervous system in animal models and humans indicate that it is both plausible and possible that this form of energy can be employed as a neuroweapon.[56–58] Interestingly, a review of the relevant literature indicates that pulsed low-intensity radiofrequency and microwave radiation can produce a series of symptoms such as headache, fatigue, dizziness, irritability, anxiety, forgetfulness, impaired concentration, and internal sound perception in affected personnel.[57] While the exact mechanism of these symptoms has not been determined, there is evidence to suggest that internal sound perception can be generated from radiofrequency or microwave exposure by the conversion of electromagnetic waves to thermoacoustic waves and that these disturbances can be mechanically transmitted through the head and detected by the sensitive hairs of the cochlea.[59] It is significant to note that symptoms similar to the neurological complaints that were reported by both American and Canadian diplomats suffering from Havana syndrome in Cuba and China between 2016 and 2018 can be reproduced by radiofrequency or microwave exposure in the laboratory setting.[60,61] It is also significant that many of the affected personnel developed chronic symptoms requiring neurocognitive testing and diagnostic imaging, which demonstrated multiple functional and structural impairments. These impairments included blood-brain barrier injury, abnormal paroxysmal slowing events of cortical activity, evidence of reduced fiber density in the fornix and the splenium, regional gray and white matter volume changes, and changes in the functional connectivity of the auditory and visuospatial subnetworks.[62] Moreover, laboratory analyses of some of the victims indicated reduced levels of cholinesterase activity and the presence of organophosphate

compounds, suggesting either intentional neuroweapon use or unintentional chemical exposure.[63] Without a clear diagnosis, no specific therapy could be administered. The victims are currently undergoing follow-up evaluation and neurocognitive rehabilitation, and their prognoses are currently unknown.

In addition to pulsed radiofrequencies and microwaves, electromagnetic gradients and magnetism have been shown to induce currents in conductive tissue and result in peripheral nerve activation that can be experienced as muscle twitches.[64] Exposure to strong electric fields has been found to produce immobilization or stimulation of pain receptors directly without thermal effects.[65] These properties of electromagnetic radiation are currently being investigated for military applications. Research into pulsed energy projectile technology has produced plasma at the target surface using lasers. This plasma can be heated with subsequent laser pulses to form a shockwave or to produce local electromagnetic effects of sufficient strength to affect the target nervous system with the aim of immobilizing or incapacitating the target.[66] As technology advances and the understanding of the interactions between the nervous system and nonionizing radiation becomes more mature, it is likely that directed energy neuroweapons will become common.

## Conclusion

All complex systems are susceptible to attack. The central nervous system is a complex structure composed of multiple substructures. It integrates information from throughout the body and formulates the appropriate behavioral and physiological responses that are necessary to enable the survival of the organism and allow the emergence of cognition. This system is responsible for the mental abilities that define the genus *Homo* and separates them from the non-human primates. The information processing power, mental model development, and decision-making ability of the human central nervous system are all essential for projecting combat power and for countering peer and non-peer adversaries. Malevolent applications of neuroscience in the form of biological neuroweapons, chemical neuroweapons, or directed energy attacks are becoming likely as the systems-level understanding of the nervous system matures. It is essential that military medical personnel monitor these developments and remain up to date on the advances in neurotechnology and how they may impact the health of military personnel. This is especially true for Special Operations medical personnel who deploy frequently and may be assigned to U.S. embassies in countries with access to sophisticated neurotechnology. It is therefore recommended that military medical personnel be made aware of the potential for neuroweapons and the various forms that these weapons can take. This will make them better prepared to recognize and respond to the effects of biological, chemical, or directed energy neuroweapons.

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