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TIP OF THE SPEAR, EDGE OF THE MIND: NEUROTECHNOLOGY'S ROLES IN THE FUTURE OF SPECIAL OPERATIONS

BY ANNA M. GIELAS, PHD



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Introduction

Rapid technological advancements are revolutionizing human augmentation, making cognitive and physical enhancements for military personnel not only feasible but also a priority for global superpowers such as the United States and China. As technology advances and global competition intensifies, military scholars explore ways to enhance U.S. Special Operations Forces (SOF) through emerging technologies such as brain-computer interfaces (BCIs). However, current debates on cognitive and physical enhancement tend to focus on mitigating perceived operator limitations, rather than exploring the full potential of both the human and the technologies.

“As early adopters of new technologies and first movers, SOF must carefully evaluate how to integrate brain-computer interface technologies and assess the implications of their use.”

Instead of merely compensating for weaknesses, enhancement technologies should be leveraged to amplify operator strengths. BCI technologies offer the potential to harness operators' inherent resources, such as tacit knowledge, and unlock latent human capabilities while reinforcing the SOF ethos that humans are more important than hardware. Additionally, to fully realize the technological potential, it is important to distinguish between

enhancing the operator and augmenting the mission—two closely interrelated yet distinct goals that demand tailored strategies. This dual focus is explored through a series of practical examples, illustrating the transformative and nuanced applications of emerging BCI technologies. Ultimately, these capabilities could enable more precise, adaptive, and deniable special operations within the evolving context of strategic competition and integrated deterrence.

The Brain-Computer Interface Future Is Already Here

Imagine paralyzed individuals walking again.¹ Or operators controlling drones through thought and communicating telepathically.² Scientists have already demonstrated the feasibility of all three.

These significant advancements are made possible by BCIs—technologies that establish a direct link between the human brain and external devices, eliminating the need for physical controls or verbal commands.³ While BCIs are not yet mature enough for large-scale integration into the armed forces, several U.S. Department of Defense (DoD) organizations, including the Defense Advanced Research Projects Agency (DARPA) and the Army Research Laboratory, are developing these technologies.⁴ Their objective is to augment warfighter capabilities in various ways—including modulating brain activity to enhance cognitive and physical performance.⁵ According to the RAND Corporation, BCI technologies will become available to the U.S. military around 2030.⁶

As early adopters of new technologies and first movers, SOF must carefully evaluate how to integrate BCI technologies and assess the implications of their use.

Currently, the global race for BCI dominance is intensifying.⁷ The Chinese Communist Party has made substantial investments in BCI research, aiming to position China as the world leader in these technologies by 2030.⁸ Some experts suggest that China may develop and deploy reliable BCI technologies ahead of the United States and highlight the potential of these neurotechnologies to define future warfare.⁹ At the same time, private companies are driving rapid innovation. In 2024 and early 2025, Synchron, in collaboration with NVIDIA, and Elon Musk’s Neuralink achieved major technological milestones, demonstrating the accelerating pace of development.¹⁰ Musk, a vocal advocate for human-machine integration, has asserted that “humans must become cyborgs if they are to stay relevant in a future dominated by artificial intelligence.”¹¹ Given the transformative, geopolitical, and military significance of BCIs, it is critical to advance the discussion of the unprecedented opportunities and unique risks that these technologies present for U.S. SOF and their missions. As early adopters of new technologies and first movers, SOF must carefully evaluate how to integrate BCI technologies and assess the implications of their use.¹²

Current scholarship on SOF enhancement includes debates of BCIs, which generally fall into two distinct categories. The first approach focuses on the use of enhancement technologies to mitigate perceived human limitations.¹³ This perspective views some biological and cognitive processes—such as fatigue, cognitive overload, and the need for sleep—as hindrances to optimal performance.¹⁴ BCIs are framed as solutions, enabling operators

to maintain high levels of effectiveness over extended periods. The second category of scholarly debate takes a more futuristic approach, exploring the replacement of human organs and physiological processes with advanced artificial counterparts.¹⁵ This approach reimagines SOF as “techno-shaped, software-defined special operations assemblages.”¹⁶ It explores replacing natural eyes with artificial ones to provide capabilities beyond human norms, such as night vision and infrared detection.¹⁷ These two scholarly lines of thought reflect a fundamental debate: whether enhancement should be confined to countering existing human limitations or expanded to redefine the very nature of the operator. However, both perspectives largely frame enhancement as a response to what SOF lack, rather than as an opportunity to build on their existing strengths.

A Third Approach

There is a third viable approach to enhancement—one that shifts the focus from perceived human limitations to the often-overlooked strengths of the operator that could be amplified through future BCI technologies. These latent capabilities include resources, such as tacit knowledge, and well-honed skills, like fine motor control. Moreover, to fully leverage technological potential, it is helpful to distinguish between enhancing the operator and enhancing the mission—two interconnected but distinct approaches to BCI integration. Mission enhancement emphasizes the use of BCIs to bolster operational stealth, such as evading detection, and aligns with United States Special Operations Command’s (USSOCOM) “security through obscurity” approach in



Current scholarship on SOF enhancement includes debates on brain-computer interfaces, focusing on mitigating human limitations and exploring advanced artificial counterparts. A third approach suggests amplifying latent operator strengths through brain-computer interface technologies, distinguishing between enhancing the operator and the mission. Source: Author-supplied Canva stock image

“hyper-transparent battlefields.”¹⁸ Drawing a clear distinction between operator-focused and mission-based enhancement encourages a broader and more creative perspective on BCI-based SOF augmentation. This conceptual shift is illustrated through a series of practical examples. Ultimately, it underscores how future BCI-based applications could enhance the precision and deniability of special operations within the framework of gray-zone activities and U.S. integrated deterrence.

A Brief Overview of Brain-Computer Interface Technologies

Neurotechnologies encompass any device designed to monitor or influence activity in the brain and other parts of the nervous system.¹⁹ Among these, BCIs are novel because they establish a unique pathway between the brain and the external world. Humans typically engage with their

environment through natural sensory inputs—vision, hearing, touch, smell, and taste—and communicate through movement and speech. In contrast, BCIs bypass these established sensory and motor pathways by translating brain signals into digital signals, which enables technological devices to execute human intentions.²⁰ This translation increasingly relies on AI and machine-learning algorithms, which have “dramatically enhanced BCI capabilities.”²¹

While BCI applications involve multiple distinct processes, a typical BCI system consists of three key components: 1) a sensor that tracks and records brain signals; 2) a decoder relying on AI that processes raw brain signals into actionable commands; and 3) an effector that executes the commands.²² In theory, any device capable of receiving and executing digital commands can serve as an effector in a BCI system, from a wheelchair to a drone swarm—highlighting the vast potential of BCI technologies.

Brain-Computer Interface Applications to Date

Since BCIs originated in the medical field, many of their applications to date have involved computers and speech-generation systems as effectors. For example, in a study from 2021, a volunteer with a spinal cord injury—who was unable to move the hand—imagined handwriting words. This mental activity generated distinct electrical signals in the brain’s motor region, which the BCI system identified and translated into text.²³ The computer typed the imagined words and sentences. The communication rates achieved in this study were comparable to those of able-bodied individuals typing on smartphones, underscoring the significant potential for patients with severe motor impairments.²⁴ Currently, most BCI research and development remain focused on medical applications, particularly for individuals with conditions such as amyotrophic lateral sclerosis (ALS) and other neurodegenerative diseases.²⁵ Given that the U.S. Department of Veterans Affairs classifies ALS as a “service-connected condition,” ongoing clinical trials may be of interest to some former USSOCOM personnel.²⁶ These studies explore how BCIs can restore communication abilities and improve the quality of life for affected individuals. For example, in a 2024 study, researchers successfully tested a BCI system that translated the brain signals of an ALS patient into text. The text was then vocalized using text-to-speech software designed to replicate the patient’s original voice.²⁷

The medical sector is not the only field poised to benefit from BCIs.²⁸ Premier scientific institutions, such as the Royal Society (United Kingdom), have emphasized the potential of BCIs to “enhance or

“**Brain-computer interfaces can be designed as invasive implants and non-invasive wearables. Invasive BCIs are placed surgically either on the surface of the brain (semi-invasive) or deeper into brain tissue (fully invasive).**”

supercharge the brain itself.”²⁹ They envision a future in which BCI “devices could help us remember more, learn faster, make better decisions more quickly and solve problems, free from biases. Training could be transformed by the ability simply to ‘download’ new skills.”³⁰ However, for this vision to become a reality, distinct challenges must be addressed—particularly the risks associated with invasive BCI hardware.

Invasive Implants, Non-Invasive Wearables, and Associated Risks

BCIs can be designed as invasive implants and non-invasive wearables. Invasive BCIs are placed surgically either on the surface of the brain (semi-invasive) or deeper into brain tissue (fully invasive).³¹ While the surgical approach carries higher risks of complications and requires recovery time, it currently enables more reliable signal acquisition, allowing for better control over external devices.³² In contrast, non-invasive BCIs—such as caps, headsets, and helmets—do not require surgery.³³ However, these devices offer less reliable performance compared to their invasive counterparts because the skull can attenuate and distort brain signals.³⁴ Despite this

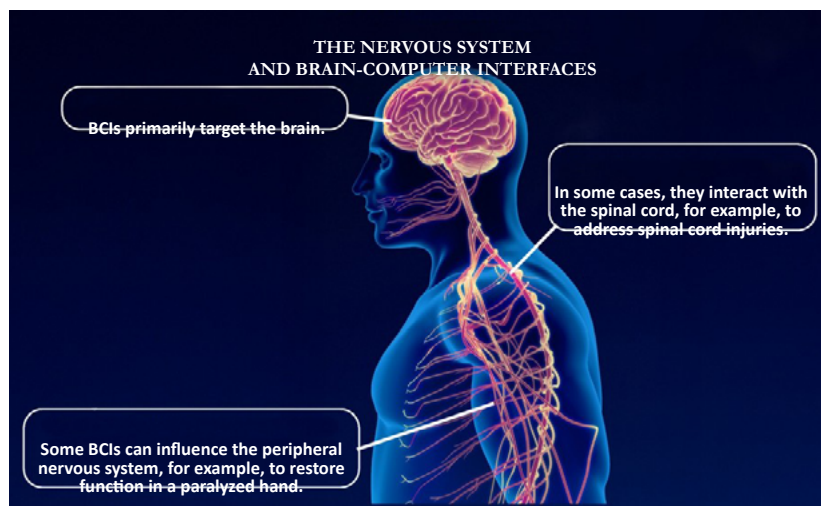
limitation, non-invasive BCIs are generally preferred due to their greater safety and ease of adoption.³⁵ To improve the performance of wearable BCIs, researchers increasingly integrate machine learning and deep learning algorithms.³⁶ Additionally, they are developing minimally invasive alternatives that can be sniffed, swallowed, or injected—bypassing many of the safety risks associated with traditional invasive implants.³⁷

For a BCI to enhance the cognitive and physical capabilities, it must be bidirectional, also referred to as closed loop. Unlike unidirectional BCIs, which focus solely on translating brain signals into commands for devices, bidirectional BCIs modulate specific brain activity. This concept is illustrated by a study carried out in 2021.³⁸ It involved a bidirectional BCI system paired with a robotic arm. In this study, the volunteer was able to control the prosthetic arm using thought (brain-to-effector), while the BCI simultaneously delivered electrical stimulation to the brain region responsible for sensory perception. This dual functionality allowed the individual

to perceive the strength of their grip (effector-to-brain), making the interaction more effective and natural.³⁹ This and similar studies underscore the potential of bidirectional BCIs to provide more intuitive prosthetic control for individuals with motor impairments.⁴⁰

BCIs can be designed as invasive implants and non-invasive wearables. Invasive BCIs are placed surgically either on the surface of the brain (semi-invasive) or deeper into brain tissue (fully invasive).

Currently, stimulation-based BCIs are primarily employed in medical applications, such as managing epilepsy. In individuals with drug-resistant epilepsy, these BCIs monitor brain activity, detect seizure patterns, and deliver targeted electrical stimulation to prevent seizures.⁴¹ Beyond epilepsy, stimulation-based BCIs hold significant promise for treating psychiatric and other neurological conditions, such as treatment-resistant depression, Parkinson's disease, and chronic pain by modulating the neural circuits implicated in these disorders.⁴²



A digital rendering of the human brain, highlighting neural activity and connections, represents the potential of brain-computer interfaces to enhance cognitive and physical functions. While these applications remain largely within the realm of clinical research, these advancements could revolutionize the capabilities of SOF by addressing injuries and restoring functions in paralyzed limbs. By integrating seamlessly with the nervous system, brain-computer interfaces may open new frontiers in human augmentation, pushing the boundaries of what is possible in both medical rehabilitation and performance enhancement. Source: Author

Scientists suggest that targeted brain stimulation enabled by bidirectional BCIs could enhance cognitive and physical abilities in healthy individuals.⁴³ For example, stimulating specific brain regions with low electrical currents could augment focus and memory beyond natural limits, such as peak concentration or exhaustion.⁴⁴ However, such advancements also introduce unprecedented risks. As early as 1937, scientists Wilder Penfield and Edwin Boldrey demonstrated that targeted brain stimulation elicited the desire to move, revealing that external stimuli can influence human volition.⁴⁵ Today, far more advanced stimulation techniques “raise the possibility of precision implantation of specific intentions—changing not only what somebody does, but what they wish to do.”⁴⁶ A stimulation-based BCI could affect the brain in such a way that the individual might not be able to tell whether something was their intent—or generated by the AI-driven device.⁴⁷ This is why the two most pressing concerns among scientists are the threats that stimulation-based BCIs pose to an individual’s agency and autonomy.⁴⁸

Reason for Caution

Scientists and ethicists point out that neurotechnologies lack the refinement and inherent safeguards of natural neural interactions, which have evolved over hundreds of thousands of years to regulate an individual’s perception and responses to the environment.⁴⁹ As a result, they caution that even medical applications of stimulation-based BCIs could unintentionally disrupt an individual’s perception and sense of self. For example, while targeting specific brain regions to alleviate pain, BCI-based

stimulation might inadvertently interfere with other neural processes that rely on the same regions.⁵⁰ Moreover, because the nervous system is highly interconnected, altering activity in one region can trigger cascading effects across functionally linked brain areas.⁵¹ Thus, although pain may be reduced, the stimulation could impair the brain’s ability to integrate sensory input from multiple senses, forcing the individual to expend greater cognitive effort to process routine stimuli.⁵² As a result, the person might experience relief from pain but feel overwhelmed by sensory input that normally would not require significant cognitive effort. Furthermore, pain is not merely a sensory phenomenon; it also encompasses emotional and cognitive dimensions deeply tied to one’s sense of self. By modulating pain perception, a BCI might inadvertently affect these interconnected components, potentially altering self-awareness and identity.⁵³

Given the potential risks associated with stimulation-based BCIs, the next section focuses exclusively on the safer and more controllable applications of feedback-providing BCIs. While both systems are bidirectional, feedback-based BCIs do not stimulate brain activity. Instead, they deliver real-time feedback and guidance through mediators such as augmented reality glasses, gloves, and other wearable devices.⁵⁴ This approach offers a safer alternative, aiming to enhance operational stealth, situational awareness, decision-making, and physical performance without directly interfering with brain processes.

Feedback-Driven Brain-Computer Interface Applications Leveraging Operator Strengths

In the future, BCIs could leverage the inherent abilities and strengths of the human body, transforming them into more powerful and accessible resources for SOF operators. An illustrative example is DARPA's Cognitive Technology Threat Warning System (CT2WS) project, conducted between 2007 and 2012. It focused on developing a non-invasive BCI system—which included wearing a BCI cap—to detect threats in real time during surveillance operations.⁵⁵ Rather than employing emerging technology to scan the operational theater, DARPA concentrated on monitoring the warfighter's subconscious responses to their environment.⁵⁶ During testing, researchers compared the CT2WS system's performance to that of the Cerberus Scout, a state-of-the-art commercial surveillance system used by Army and Marine Corps units in 2012. CT2WS significantly outperformed the Scout, achieving a threat detection rate of 91 percent compared to the Scout's 53 percent, while maintaining an impressively low false alarm rate of five per hour—even when processing over 2,300 events per hour.⁵⁷ The core premise behind CT2WS is that the human brain continuously processes vast amounts of information, most of which remains in the subconscious.⁵⁸ While this information is often dismissed by the brain as less critical and does not surface to the warfighter's conscious attention, some of it can be highly valuable, as demonstrated by the CT2WS project.

Similarly, BCIs could become an instrument to access an operator's intuition or gut feelings, a faculty that has historically played an important role in special operations.⁵⁹ BCIs could elevate this reliance by, for instance, amplifying an operator's bad

feeling about a situation and helping them identify the source of concern. In complex, data-saturated environments, this application could direct attention more effectively to critical areas, enabling operators to make better-informed decisions under pressure. This integration of subconscious processing with advanced technology could enhance situational awareness in the future.⁶⁰

The Role of Tacit Knowledge

Eventually, BCIs could also tap into the reservoir of tacit knowledge of SOF personnel to provide actionable insights. The U.S. Army defines tacit knowledge as “a unique, personal store of knowledge gained from life experiences, training, and formal and informal networks of friends and professional acquaintances. This knowledge includes learned nuances, subtleties, and workarounds.”⁶¹ However, this definition focuses primarily on the concept of knowledge, leaving the meaning of tacit within tacit knowledge undefined. Unlike explicit knowledge, individuals are often unaware of their tacit knowledge.⁶² The polymath Michael Polanyi introduced the concept of tacit knowledge in the 1960s, stating: “I shall reconsider human knowledge by starting from the fact that we can know more than we can tell.”⁶³ He illustrated his idea with the bicycle analogy: While it is possible to describe the moves of riding a bike, one nevertheless cannot consciously pinpoint how exactly one's muscles and body align so perfectly to carry out the activity with ease and comfort.⁶⁴ According to Polanyi, an individual accumulates considerable tacit expertise through experience over the course of a lifetime.

LisaRe Brooks Babin and Alice J. Garven note that “if the military is able to identify and tap into tacit knowledge across the enterprise, it can employ the talent more quickly and effectively.”⁶⁵ By detecting brain activity associated with tacit knowledge, BCIs could surface insights. For instance, if an operator detects a weakness or contradiction in a mission plan on an unconscious level, a BCI could register neural signatures of that perception and alert the team.⁶⁶ As BCI technology advances, feedback could become increasingly granular, pinpointing not only general issues but also specific phases or elements of the mission that require attention or revision. This integration of subconscious processing and technology could transform tacit knowledge into a powerful resource for planning and decision-making.



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Tacit knowledge has been regarded as deeply related to creative thinking, both of which could be particularly helpful when SOF are tasked with developing or executing novel types of operations, such as those within the SOF-Cyber-Space Triad.⁶⁷ United

States Army Special Operations Command (USASOC) Commanding General Lieutenant General Jonathan Braga introduced the Triad in 2021. He describes it as “the convergence of trans-regional, multi-domain, and joint capabilities to exponentially increase the holistic strategic effects across the spectrum of conflict.”⁶⁸ Major Brian E. Hamel at USASOC notes in his recent master’s thesis on this topic, that “the SOF community, and by extension the stakeholders within the Triad, have not clearly defined how SOF can generate effects which impact the space domain.”⁶⁹ While current BCIs are not yet mature enough to actively identify and surface subconscious creative insights, future advancements that leverage tacit knowledge could help reimagine and rearrange existing mission elements, thereby facilitating the development of operational concepts for new frameworks like the Triad.

By detecting brain activity associated with tacit knowledge, Brain-Computer Interfaces could surface insights. For instance, if an operator detects a weakness or contradiction in a mission plan on an unconscious level, a Brain-Computer Interface could register neural signatures of that perception and alert the team.

In the future, the convergence of tacit knowledge and BCI technology could enhance creative capabilities, enabling more precise and deniable actions across the gray zone. In addition to SOF, several civilian agencies and military entities engage in gray zone activities, including the Department of State, the Central Intelligence Agency, and the Cyber Command. Given this diverse interagency involvement, leveraging BCI technology to harness SOF’s unique tacit knowledge could help the SOF community

better define its competencies and refine its role in relation to other national security actors operating in the gray zone. A clearer distinction between SOF's capabilities and those of other agencies would not only facilitate more effective integration into broader military strategies but also reduce redundancy within the interagency framework. This enhanced alignment with the broader national security apparatus would ultimately amplify SOF's impact in the gray zone, reinforcing its contribution to U.S. strategic objectives.

Leveraging BCI technology to harness SOF's unique tacit knowledge could help the SOF community better define its competencies and refine its role in relation to other national security actors operating in the gray zone.

Brain-Computer Interfaces and Fine Motor Tasks

Similar to intuitive gut feelings and tacit knowledge, scientists observe that “information about fine motor controls is not introspectively accessible to our consciousness.”⁷⁰ Today, non-invasive BCIs can capture neural activity associated with fine motor movements and monitor performance.⁷¹ In the future, they could provide real-time feedback to enhance precision in fine motor tasks, such as marksmanship or surgical procedures in the field.⁷² To achieve this, AI-powered algorithms could analyze neural signals to distinguish between optimal and suboptimal motor commands, focusing on elements such as grip strength, movement smoothness, and subtle tremor.⁷³ Haptic feedback via smart gloves could enable real-time grip adjustments, while visual feedback, delivered through augmented reality overlays, could

highlight critical details—for instance, the optimal trigger pressure or hand positioning during a high-precision marksmanship task.⁷⁴

BCIs could also improve stealth and coordination during complex maneuvers—including scaling walls, parachuting, or navigating underwater. This technology could be particularly valuable for naval SOF or those operating in maritime environments where instability and environmental challenges are the norm. Dynamic conditions, such as the motion of ships, submarines, or high-speed boats, introduce unique challenges like vibration and continuous movement. They demand exceptional stability and precision in fine motor tasks. While mechanical solutions, such as stabilization systems on attack boats, help mitigate some of these challenges, BCI devices could complement them through neuro-enhanced adaptability. More specifically, BCIs can already monitor neural signals related to motion anticipation and muscle compensation.⁷⁵ In the future, they could predict involuntary movements and enhance natural stabilizing reflexes to improve balance and precision. This could occur through feedback mechanisms, such as auditory and haptic cues, or through visual overlays that guide the operator in adjusting their posture and movement. Beyond maritime settings, BCIs could also support fine motor skills in extreme climates, where environmental factors such as intense cold or heat reduce dexterity and impair performance. By addressing both environmental and physiological challenges, BCIs offer a promising avenue for improving operator effectiveness in complex and high-stakes conditions.

Envisioning the warfighter of 2050, scientists suggest that the human eye could be “completely replaced, and data feeds pass directly into the optical nerve bundle behind the eye. The sensory input for visualization would be completely mechanical or electronic in composition.”⁷⁶ As long as such enhancements are neither safe nor deemed acceptable by warfighters, BCIs could be used to integrate visual and auditory data from the operator, as well as specialized external sensors, to maximize situational awareness.⁷⁷ These sensory inputs—visual, auditory, or otherwise—would be processed by AI algorithms designed to identify patterns and correlations relevant to the mission. The AI would monitor which sensory data the operator’s brain engages with most actively and where processing is slower or insufficient. Based on this analysis, real-time feedback could be delivered through sensory cues or augmented reality overlays, optimizing the operator’s attention, responsiveness, and ultimately, situational awareness. While the underlying principles of such applications—particularly the fusion of visual and auditory data—have been extensively researched, their implementation in complex, high-stakes environments remains an area of ongoing development.⁷⁸

Unidirectional and Bidirectional Brain-Computer Interface Applications for Mission Enhancement

Similar to strategies proposed by scientists for pilots and air traffic controllers to minimize human error, BCI systems could dynamically allocate tasks based on cognitive workload, optimizing performance

in high-stakes environments.⁷⁹ For example, during a future mission, the team could be divided into operators responsible for different tasks including breaching, clearing rooms, and securing perimeters. In such scenarios, cognitive load among operators may vary drastically depending on factors such as task complexity. Each operator might wear a lightweight, non-invasive BCI device designed to monitor neural activity related to cognitive processes such as attention and fatigue. These devices would transmit data to an AI-driven BCI system, which could analyze each operator’s mental state in real time.⁸⁰ If the system were to detect that the operator responsible for breaching was experiencing heightened cognitive load and fatigue—perhaps due to unexpected material resistance at the entry point—while another operator assigned to perimeter security remained underutilized, the system might reallocate tasks accordingly. The less fatigued operator could be reassigned to assist with breaching, while perimeter monitoring would be temporarily transferred to an autonomous drone or another team member. This dynamic distribution of workload has the potential to reduce the likelihood of errors, thereby enhancing the safety of both the breacher and the team.⁸¹ Moreover, aligning tasks with operators’ cognitive states could strengthen team cohesion. In newly formed teams, such adaptive strategies might accelerate the development of synergy and trust; in established teams, they could transform inefficient task dynamics and foster adaptability in unpredictable scenarios. Ultimately, the integration of cognitive-state-based task allocation can augment both performance and mission outcomes.

In 2009, DARPA worked on the Silent Talk project. The goal was to develop a BCI system that could enable warfighters to communicate silently through neural signals, representing a step toward “telepathic” communication.⁸² A similar application could enhance future special operations where audible or visual signals are impractical or unsafe. This technology aligns with thought-to-text applications, similar to those currently used by paralyzed patients to communicate. However, existing systems still require controlled environments for reliable operation. Deploying BCIs in the field requires advancements in ruggedness and reliability. Nevertheless, rapid progress in materials science, AI, and wearable technology is reducing these barriers, paving the way for robust, field-deployable BCI-enabled communication.⁸³

Beyond communication, BCIs have also been explored for motor function restoration in the medical field. Wearable

BCI devices integrated with functional electrical stimulation (FES) have been used to address cerebral palsy and stroke-related foot drop, aiming to improve gait.⁸⁴ The convergence of BCIs and FES technologies could theoretically be used to intentionally alter gait patterns, thereby serving as a form of biometric evasion. FES does not directly target the brain; instead, it applies electrical currents to nerves and muscles in the leg to induce muscle contractions.⁸⁵ Stimulation is typically delivered via surface electrodes placed over the target nerves or muscles.⁸⁶ This method allows to modify the stride length, cadence, and walking posture. In a hypothetical BCI-FES combination, BCIs could provide real-time input from the operator to control which muscles are stimulated and when.⁸⁷ For example, an operator could think about walking with a limp or an altered stride, and the BCI-FES system could help execute the



How future soldiers may navigate a challenging, arid landscape: Brain-computer interface technology projects tactical hands-free data displays, enhancing situational awareness and providing real-time assessment. Potential military applications of advanced brain-computer interface systems could affect a significant integration of technology for enhanced operator capabilities and missions. Source: Image generated using Google Gemini 2.5 Flash, May 20, 2025

corresponding movement pattern.⁸⁸ This application could be particularly relevant for SOF operations since gait is a reliable biometric identifier used in surveillance systems and is likely to become more widely used in the near future.⁸⁹ Unlike facial recognition or fingerprints, gait can be monitored from a distance, allowing covert surveillance even with low-resolution cameras, let alone more advanced systems like LiDAR.⁹⁰ By effectively altering gait, operators could disrupt gait-recognition algorithms, complicating efforts to track or identify them based on their walking patterns. Currently, BCI-FES integration faces challenges in activating isolated and deep muscles and remains largely limited to clinical rehabilitation.⁹¹

Another way BCI technology could enhance operations is by providing a hands-free interaction with devices, “freeing operators to focus on other tasks.”⁹² For instance, this capability would allow operators to perform physically demanding activities—such as extracting wounded teammates or scaling walls—without interrupting drone operations. In rugged or mountainous terrain, where climbing and balance demand full hand engagement, BCI-controlled drones could provide critical situational updates without the need for manual operation. By eliminating the need for hand-held controllers, BCIs would reduce the amount of equipment operators must carry, simplifying gear management. Ultimately, this technology could enhance multitasking capabilities while lightening the combat load. Moreover, by reducing physical movement and electromagnetic emissions compared to traditional interfaces,

BCI technologies could lower signatures, aligning with USSOCOM’s requirement for “comprehensive signature management approaches enabling low visibility and clandestine capabilities.”⁹³

Building on this, an important consideration in managing the signatures generated by BCI systems—and enhanceive technologies in general—is determining whether these systems should be employed by operators themselves or delegated to frontline enablers. Enablers provide specialized support to operations, offering skills “ranging from medical care, to intelligence and communications.”⁹⁴ These roles often place enablers in less contested or denied environments, where higher operational signatures may be more acceptable compared to operators directly engaged in the field.⁹⁵ Equipping enablers with BCIs could enhance their efficiency in several ways, such as real-time data analysis, coordination of drone or surveillance assets, and improved medical response times. By serving as the enhanced element in special operations, enablers using BCIs could reduce the cognitive and operational burden on operators, allowing them to focus on mission-critical tasks while reducing their risk of detection. However, this approach may align better with the operational structures of SEAL platoons and Marine special operations teams, which rely heavily on enabling personnel for mission support.⁹⁶ In contrast, highly self-sufficient units, such as Special Forces operational detachments, may not integrate enabler-based BCI use and may be better suited for operator-based BCI applications.

Temporary Brain-Computer Interfaces for Tactical Edge Environments

BCI technologies could be adapted to mission duration and environment, for instance during special reconnaissance (SR). Anders Westberg observes that SR missions require operators “to blend in with their surroundings. How those collectors blend in depends on the nature of the mission as well as where and when it is executed.”⁹⁷ BCIs may, in fact, become an element of blending in. One such option is offered by digital printing of temporary sensors that enable non-invasive BCI technology and can look like tattoos.⁹⁸ Scientists have developed on-scalp digital printing techniques to create such e-tattoos that are self-drying and ultrathin and also compatible with short hair.⁹⁹ These skin-conformal e-tattoo sensors enable high-quality brain activity monitoring and could be a viable option for short-term missions.¹⁰⁰ As an element of blending in, these sensors do not stand out on operators with numerous tattoos. At the same time, BCI-enabling e-tattoos could augment operational effectiveness without relying on helmets or headsets that might raise suspicion. The tattoo-sensors can be removed with soap and water or an alcohol wipe but are currently limited in durability and may rub off during sleep. Researchers are working to improve the ink’s robustness and extend its durability.¹⁰¹ The flexibility of emerging BCI sensors not only points to the growing multitude of potential applications across the SOF mission portfolio; it also highlights how such technologies may serve dual roles beyond their primary function. Just as e-tattoos can simultaneously enable brain activity monitoring and aid in visual

concealment, future BCIs may similarly provide both operational and contextual advantages. These technologies could dynamically adapt to mission-specific needs, extending their utility beyond their core technological purpose.

Human-Machine Trade-Offs in the Hyper-Enabled Battlespace

Unidirectional and feedback-based bidirectional BCIs have the potential to act as force multipliers, enhancing situational awareness, decision-making, innovative thinking, and physical performance. These capabilities align closely with the objectives of the Hyper-Enabled Operator (HEO) program—first announced in 2018—which aims to empower SOF through technologies that “accelerate tactical decision making by increasing situational awareness, reducing cognitive workload, and simplifying mission appropriate information sharing.”¹⁰² BCI integration with other HEO sensors could further amplify their utility, enabling a more seamless and data-driven operational ecosystem.¹⁰³ However, BCIs also introduce significant complexity, particularly in terms of integration, usability, and reliability. Without careful design, they risk overwhelming operators with excessive data or failing to perform effectively in high-stakes environments. To maximize their advantages while mitigating risks, BCIs should be introduced as optional, modular components within the HEO ecosystem. A phased approach—starting with non-critical applications such as monitoring cognitive load—would help establish their reliability and operational value before incorporating them into mission-critical systems.

As the SOF enterprise explores integrating tested BCI devices and other AI-based enhanceive technologies, it is critical to recognize that these advancements come with significant training demands before they can be deployed safely and effectively. Unlike traditional equipment upgrades, BCI technologies require SOF to develop new cognitive and adaptive skills, adding to their already rigorous training. Special Forces Officer Kyle Atwell notes that integrating new technologies is “conceptually wise, but organizationally difficult” given that operators and other SOF personnel already operate under considerable time constraints.¹⁰⁴ Thus, the challenge is not only learning to use BCIs effectively but also determining how to integrate them without diminishing other core SOF competencies. Kendrick Kuo of the U.S. Naval War College cautions that technological innovation can lead to the erosion of long-established capabilities, potentially creating operational vulnerabilities.¹⁰⁵ This raises a critical question: What trade-offs should the SOF community be willing to accept? Consider the following dilemmas: Should snipers prioritize human-machine teaming to achieve world-class marksmanship, even if it means they become significantly less effective without the BCI system? How could medical sergeants incorporate BCI-assisted procedures that enable lifesaving interventions previously deemed impossible while ensuring they retain the ability to operate in austere environments where such technology might be (come) unavailable? Should certain SOF roles impose limits on BCI integration to prevent over-reliance and ensure adaptability in degraded operational conditions? While

these scenarios may seem speculative, they highlight a central challenge of enhancing technologies: ensuring that SOF operators remain highly capable, whether enhanced by AI and BCIs or operating independently of them. Successful integration requires not only technical training—but also strategic decisions on when, where, and how to employ these technologies without compromising the agility, adaptability, and resilience that define SOF.

Technology to Serve Both Human and Mission

In an era of intense geopolitical competition and rapid development of AI-driven technologies, militaries are increasingly tempted to pursue new methods of soldier enhancement. The justification for such enhancement often rests on the perceived limitations and fragility of the human operator.¹⁰⁶ Framing the healthy human body and mind as inherently deficient—and in need of technological intervention—suggests that AI-based neurotechnologies are both necessary and worth the associated risks. This narrative is ethically troubling because it can pressure service members into adopting neurotechnologies even when the risks outweigh the benefits. Over time, this narrative may also normalize the perception of healthy operators as inadequate without neurotechnological augmentation, fostering a culture of dependency. A growing reliance on neurotechnologies could reshape the identity of SOF, shifting the foundation of effectiveness from human skill, creative adaptability, and judgment to technological capabilities.

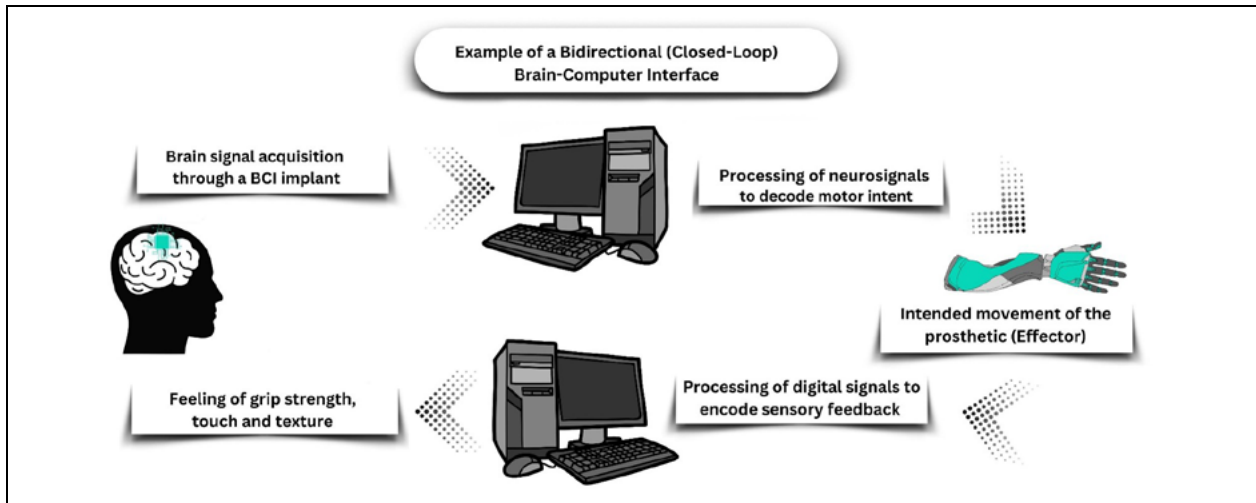


Figure 1. An example of a bidirectional (closed-loop) brain-computer interface workflow. The process involves brain signal acquisition, decoding motor intent, and controlling a prosthetic. The system also provides sensory feedback, allowing the user to feel grip strength, touch, and texture. Source: Author-created workflow

Some SOF scholars already anticipate such a future, wondering “whether humans will continue to be more important than hardware.”¹⁰⁷ While this concern is understandable, it reflects a troubling willingness to prioritize machines over humans—and is fundamentally flawed. Whether a stone axe 5,000 years ago or an AI-based BCI 5 years from now: both are expressions of human intentions, human creations, and means for humans to achieve their goals. In light of this, SOF should not allow advanced technologies to define the value and role of the human operator. Similarly, the question should not be whether humans or machines are more important—but how technology can best serve the mission and, at the same time, bolster human skill, creativity, safety, and ethical responsibility.

Distinguishing between enhancing operators’ inherent strengths and augmenting mission capabilities has helped identify potential future BCI applications. Notably, mission enhancement through

BCIs does not necessarily require direct cognitive or physical enhancement of the human. For instance, the temporary impairment of an operator’s gait to evade biometric surveillance—alongside other examples discussed—illustrates that neurotechnological applications can augment the mission through the tactical disenchantment of the warfighter. This does not only suggest the potential of the machine but also invites a more creative approach to the human. It reframes the operator not as a fixed unit of optimization but as the perpetually adaptable agent—capable of disrupting and subverting adversary AI-based expectations. In this light, the future of BCI-driven special operations may lie less in offsetting human limitations and more in reimagining how operators and machines co-construct advantage in environments defined by ambiguity, surveillance, and rapid change. This approach helps guard SOF against a reality in which “our machines are disturbingly lively, and we ourselves frighteningly inert.”¹⁰⁸

Acronym List

AI - artificial intelligence

ALS - amyotrophic lateral sclerosis

BCI - brain-computer interface

CT2WS - Cognitive Technology Threat Warning System

DARPA - Defense Advanced Research Projects Agency

DoD - Department of Defense

FES - functional electrical stimulator

HEO - hyper-enabled operator

SOF - Special Operations Forces

SR - special reconnaissance

USASOC - United States Army Special Operations Command

USSOCOM - United States Special Operations Command

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