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THE BRAIN COMPUTER INTERFACE FUTURE:

TIME FOR A STRATEGY

by

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Biography

Lieutenant Colonel Brian E. Moore is an U.S. Air Force Biomedical Science Corps officer and physician assistant assigned to the Air War College, Air University, Maxwell AFB, AL. He graduated from the University of Nebraska with a Bachelor of Science degree in 1993 and a Master of Physician Assistant Studies with a concentration in Family Medicine in 1997. He also graduated from The Uniformed Services University of the Health Sciences in 2004 with a Master of Public Health. Lieutenant Colonel Moore has completed the U.S. Army Flight Surgeon Course and an emergency medicine fellowship at Wright-Patterson Medical Center. Along with numerous clinical assignments, he has served at the Defense Medical Readiness Training Institute, HQUSCENTCOM, and the White House Medical Unit. He is a graduated squadron commander.

Abstract

Brain-computer interface (BCI) technology, a subset of human-machine interface, will impose significant utility, relevance, and strategic advantage with national security opportunities and challenges. This technology will advance computing speed, cognitive decision-making, information exchange, and enhanced computational power, resulting in substantially enhanced human performance. A direct connection between the brain and a computer will bypass peripheral nerves and muscles, allowing the brain to have direct control over software and external devices. The military applications for communications, command, control, remote sensors, and weapon deployment with BCI will be significant. Currently this technology is confined to the rehabilitative medicine community for persons with disabilities and the computer gaming industry; however, China, India, Iran, Russia, Japan and European nations are actively working to improve existing electroencephalography, magnetic resonance, functional infrared, and the magnetic encephalography spectrums to develop future military applications. Similar to the experience with computer and networking technology, rapid advancements in neurotechnology will render BCI regulation increasingly challenging. This potential vulnerability will place our infrastructure and individual persons at high risk. The ability to penetrate human brains through BCI will add a new dimension to physical and cyber security. Additionally, moral, ethical, and legal issues will challenge BCI application and employment in the United States. Finally, by 2032 this technology has the potential to revolutionize military dominance much the same way nuclear weapons have done. To maintain the competitive advantage with competitor nations, it is time develop a strategy for the United States and the Air Force to lead in research, design, manufacturing, employment, exploitation, security and counterproliferation of this technology.

Introduction

"We don't see with our eyes, or feel with our hands; we see and feel with our brains."[1]
Paul Bach-y-Rita, pioneer in the field of sensory substitution, University of Wisconsin

In the past twenty years neuroscience has made significant progress on understanding human brain function. Likewise, the computational powers of computers have increased exponentially in this same period. Therefore, it is of no surprise that research advancements in brain-computer interface technology (BCI) are developing. Brain-computer interfacing started in the 1970s at the University of California, Los Angeles under a grant from the National Science Foundation,[2] and it is defined as a hardware and software communications system that bypasses peripheral nerves and muscles and permits cerebral activity to control computers or external devices.[3] Neuroscience advances in wearable biosensors, data acquisition, and mobile brain imaging have triggered a fresh wave of research. The ability to assist individuals with lost function from disease or injury with this technology has been remarkable, and the next evolution of brain-interfacing technology is already underway. Researchers worldwide have already begun studying ways to apply brain-computer interfacing outside the rehabilitative realm. Brain-computer interface technology, a subset of human-machine interface and human performance enhancement technologies will provide increased utility, relevance, and strategic advantage over the next two decades. The United States Air Force needs to be postured to secure, exploit, and employ brain-computer interface technology, with the ability to deny and deter its use by foreign competitors.

BCI research has already captured commercial interests and the potential for military application. It is likely that BCI technology will dominate military systems in 2032. By linking computers to the brain's activities, new devices will take technology a giant leap forward. Imagine a remotely piloted air vehicle, sea vehicle or ground weapons system with an array of sensors and weapon systems that transmits and receives data input directly to and from the human operator's brain at an unprecedented rate, eliminating the delay of human sensory and muscle movement information processing. The operator's brain-computer interfacing could provide a multi-dimensional view of the battle space real-time with constant analysis and cognitive intuition. A fundamental difference between the brain and the computer is the brain uses billions of cells in parallel organization, whereas computer transistors are organized sequentially, and electronic computers operate at speeds millions of times faster than brain computing. The brain has significant computational breadth, but limited depth. In contrast, computers have the depth to run an algorithm at high speed with significant data storage, but have limits on running multiple algorithms simultaneously.[4] Currently this mismatch limits BCI effectiveness, but the pace of computing and neuroscience research will solve this mismatch in the coming decades.

It is therefore imperative that the United States leads in this technology through sound policy and strategy that ensures national security, protects interfaced systems, individuals and personal privacy. This technology has the ability to enhance American military dominance much the same way that nuclear weapons have since World War Two. On the other hand, potential adversaries could take the lead in BCI technology and place the United States at a significant strategic technological disadvantage. In 2006 the Chinese government initiated the Medium and Long-Range Program for Science and Technology development, a strategy to enhance the country's innovation and technological competitiveness, including BCI technology.[5] Now is the time for a strategy for the United States to lead in research, design, development and application of this emerging technology.

This paper will build the argument that this crucial innovation is strategically vital and will begin by briefly examining current and future BCI modalities in regards to signal measurement and control. In addition, this research will provide an overview of worldwide leaders in BCI technology and commercial development, and will address potential future applications, and security, privacy, ethical, and legal ramifications of this emerging technology. This paper will conclude with strategy recommendations and build the case for a strategy to lead this critical emerging technology.

BCI Current Modalities

Fundamentally, BCI is the utilization of brain signals to gather information on use intentions.[6] BCI systems can be characterized as either invasive or non-invasive, wherein invasive systems require cortical or surgical implantation of electrodes to acquire signals, or non-invasive signal gathering through external electrodes on the scalp. The standard BCI system operates within the context of the following steps: signal acquisition, preprocessing and signal enhancement, feature extraction, classification, and interface control.[7]

Signal acquisition consists of three neuroimaging modalities that function by monitoring brain activity, either electrically, magnetically or metabolically. Second, the preprocessing stage prepares the signals, followed by feature extraction which identifies discriminative information from the brain signals. This extraction is very difficult due to distortion and artifact, and once the extraction is complete and classified the control interface translates the signals into meaningful commands. Traditionally the idea of deciphering thoughts and intentions was deemed complex and remote, however in the past twenty years it has expanded tenfold.[8] This expansion is still relatively young, and despite a convergence of research from neuroscience, physiology, psychology, computer science, engineering, and rehabilitation disciplines there is wide variation in BCI technologies. [9] The research community has signaled the need for a general design framework model and comparison and evaluation of BCI designs will foster development and synchronization of multinational collaborative research programs.[10] Developing the design of a BCI framework model will allow the United States to lead and exercise control of BCI as it emerges from the laboratory and medical rehabilitative areas into military and commercial applications. This begins with a very basic understanding of brain electrical and hemodynamic physiology.

Electrophysiological Measurement

In the brain, electrophysiological activity generates information exchanges through ionic currents between neurons through electro-chemical transmitters. This electrophysiological activity can be measured by electroencephologography (EEG), electrocorticography (ECoG), magnetoencephalography (MEG), or signal activity at the individual neuron level.[11] Another way to indirectly measure electrophysiological activity is through hemodynamic response with functional magnetic resonance imaging (MRI) or near infrared spectroscopy. Currently EEG is most the most widely used BCI interface due to high temporal resolution, less user risk, and lower costs.[12] EEG technology has been widely available for many decades but has significantly expanded as researchers have developed improved ways to capture and interpret signals. EEG signals are emitted in five frequencies and are easy to measure non-invasively; however, signal noise from inside the brain, skull, and scalp tissue results in diminished signal quality. The signal-to-noise ratio can be increased with the use of a conducting gel in combination with the electrodes, or with newer, “dry” electrodes made of titanium and stainless steel. These five frequencies span awake and sleep states, visual, auditory, and motor processing. The gamma frequency is becoming more attractive to BCI research because it seems to offer increase transfer rate and spatial specificity. [13]

Two growing areas of interest are MEG and ECoG. MEG measures intracellular currents by magnetic induction. The MEG is physiologically identical to EEG but is more sensitive and provides higher spatiotemporal resolution with less distortion by bone and tissue of the skull and scalp.[14] The current disadvantages of MEG are high cost and increased equipment size. ECoG provides a direct measurement of cerebral cortex electrical activity on the brain's surface. This modality requires invasive access and is currently confined to animal research only. In the United States the direction of this research is aimed towards confined persons with severe motor disabilities.[15] As these technologies mature, they will become increasingly more viable for BCI applications.

Hemodynamic Measurement

Functional Magnetic Resonance Imaging (fMRI) and Near Infrared Spectroscopy (NIRS) are two non-invasive, hemodynamic measurements of neural activity. Early fMRI provided low temporal resolution due to significant hemodynamic delays and thus was deemed not well suited for communication in BCI systems; however, recent research using fMRI to measure the blood oxygen level during activation of neurons has led to a more real-time utilization of fMRI and expanded possibilities with BCI. NIRS employs infrared light to penetrate the skull and record fluctuations in cerebral neural activity through measuring oxyhemoglobin and deoxyhemoglobin concentrations. Like fMRI, the main limitation is the slowness of the hemodynamic response, but it has lower costs and is more portable than fMRI. Thermoplastic molded helmets are being used to decrease head motion artifact, and NIRS appears to be a good alternative to EEG for future BCIs.[16] Like MEG and ECoG, medical researchers in the United States lead in this technology.

EEG and Event Related Potentials

As previously stated, EEG is currently the technology receiving the most focus for BCI application. EEG BCIs interpret user intentions through monitored cerebral activity and a multitude of cognitive tasks. This requires an event-related potential (ERP) electrophysiological response to an internal or external stimulus.[17] These ERPs are control signals and can be defined by signal types: P300, steady state visual evoked potential (SSVEP), event related desynchronization (ERD), and slow cortical potential based.[18] The P300 BCI was introduced in 1988 but had very little peer-reviewed research until recently.[19] Between 2000 and 2010 there was a ten-fold increase in peer-reviewed research on P300 BCI.[20] The P300 potentials have emerged as the leader in BCI categories and manifest as positive peaks in EEG due to auditory, visual, or somatosensory stimuli. An important aspect of P300 BCI is that it requires eliciting large differences between target and non-target EPRs, traditionally requiring a visual row and column paradigm on a computer display. Row and column paradigms rely on an alphabetic and numeral speller on a computer screen, allowing the interface user to elicit a P300 response by focusing on the desired character. The P300 speller has been the benchmark for P300 BCI systems.[21] Today research is expanding beyond this paradigm.

Other areas aside from evoked potentials, such as sensorimotor rhythms, are growing in interest. Sensorimotor rhythms are composed of mu and beta rhythms, that are localized brain activity that can be measured. The mu, or Rolandic, band occurs in the 7-13 Hz range, and the beta band occurs between 13-30 Hz, and these sensorimotor rhythms have been used to control BCIs and predict human voluntary motor movements before they occur.[22]

BCI Research and Trends

This overview of BCI technology outlines the variation of research worldwide. BCI research in North America is predominantly focused on invasive modalities for medical and rehabilitation application, whereas Europe and Asia are almost exclusively engaged in non-invasive BCI research for non-medical applications. Japan is particularly focused on BCI and robotic integration.

Cooperative Research

The World Technology and Evaluation Center (WTEC) Panel Report sponsored by the National Science Foundation (NSF) in 2007 recognized several major BCI trends. First, BCI research worldwide is extensive and on the rise. Second, the rapid rate of medical application of BCI will result in future nonmedical commerce initially in the gaming, and the automotive, robotics industries. Third, the WTEC found the BCI focus worldwide was uneven with significant opportunity for synergistic and productive corroboration.[23] BCI research is multidisciplinary, with significant research overlaps in biology, neuroscience, computer science, neurology, neurosurgery, neuropsychology, bioengineering, bio-manufacturing and miniaturization. The WTEC concluded that industry and academic leaders in Europe and Japan have taken steps towards developing BCI-related, integrated research goals.[24]

BCI Research in Europe

Overall the WTEC report determined that the European researchers were committed to long-term, interdisciplinary research, and the European Union system more readily created multidisciplinary teams. Further, the scale of European BCI research projects and funding exceeds that found in the United States, and only the NSF Engineering Research Center collaboration with the University of Southern California and the Defense Advanced Research Project Agency (DARPA) prosthetic research compete with these programs.[25] Austria and Germany are emerging as the European leaders in BCI research at Graz University of Technology, Guger Technologies, and the Berlin BCI Interface Project. Researchers at the University of Türbingen are focused on noninvasive fMRI and MEG, and have been recognized as both the 2011 and 2012 worldwide Annual BCI Award winners in these areas. The University of Freiburg is directing research on non-linear brain function, and interdisciplinary collaboration is underway with this project between Aalborg University in Denmark and Italy's Scuola Superiore Santa' Anna, and Türbingen. Currently La Sapienza in Italy is working with Case Western Reserve and the Wadsworth Center in the U.S. on integrated BCI research projects. Finally, Russian BCI research is being led at the Moscow State University's Human Brain Research Group.

BCI Research in Asia

BCI research is expanding across Asia. China currently leads in BCI algorithm research, with a focus on cheap, low-technological solutions to BCI. The Chinese Government has made large-scale investment through the Chinese Ministry of Science and Technology, National Natural Science Foundation of China, and the China High-Tech Research and Development Program in the areas of the biological sciences, engineering, and computer science. The WTEC report concludes this investment has transformed several major universities into world-class facilities for BCI and biomedical engineering. These include: Tsinghua University, East China Normal University, Shanghai Jiao-Tong University, Shanghai Institute of Brain Functional Genomics, and Huazhong University of Sciences and Technology.[26]

Japan is just beginning to discover BCI research and seeks to integrate BCI research with its established robotic applications. Unlike the United States, Japan's BCI research is solely noninvasive and is expanding into combined fMRI, MEG, and NIRS. Researchers at the RIKEN Brain Science Institute, the Advanced Telecommunication Research Institute, Nippon Telegraph and Telephone Communication Science Laboratories, and Waseda University are taking broader steps towards BCI research. There is particular interest to integrate "normal" individuals with enhanced cognitive function, and ethical issues are already starting to emerge. With an aging population, medical and "assistive" needs for BCI will continue to grow. The Government is the primary funding source for BCI research in Japan.[27]

China and Japan are not alone in pursuit of BCI research in Asia. BCI researchers at the Islamic Azad University, Shahed University, and Khajeh Nasir University of Technology in Iran were recently published in a peer-reviewed journal in January 2012.[28] BCI research is underway in Pakistan at the North West Frontier Provincial University of Engineering and Technology, in India at the National Brain Research Center, and in Indonesia at the Institute for Infocomm Research and the Danyang Technology University.

BCI Research in the United States

In the United States BCI research is being conducted at many universities, in particular, the Wadsworth Center at the State University of New York, The Walden School of Biomedical Engineering at Purdue University, Tuffs and John Hopkins Universities. The United States Government has generated funding through the NSF, NIH Institute of Biomedical Imaging and Bioengineering, DARPA, and the U.S. Army Research Laboratory. Unlike Asia and Europe, most BCI research in the United States is focused on medical and rehabilitative applications, and the WTEC report identified the need for increased cooperation in BCI research between the United States, Asia, and Europe.

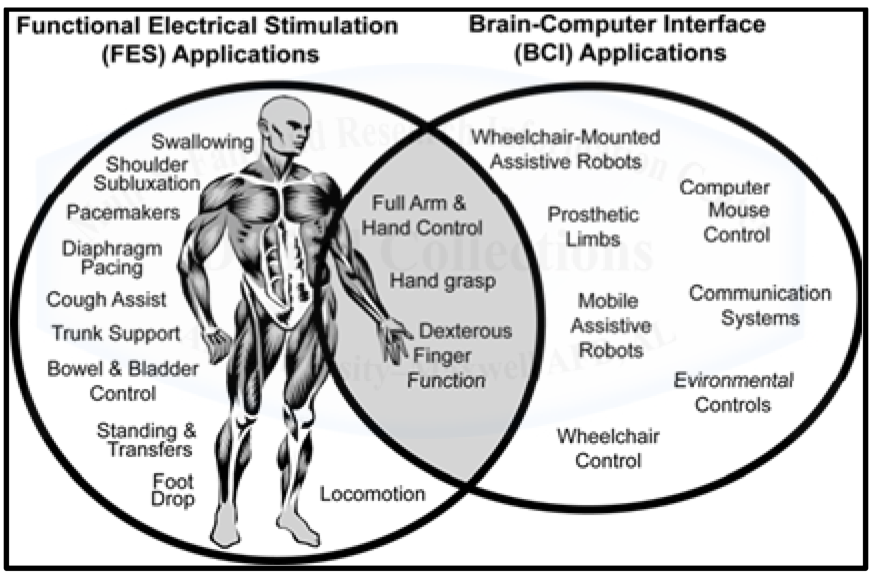
Commercial Research and Development

The potential nonmedical applications of BCI have led to commercial development, and several companies have emerged worldwide. Among the leaders are companies in the gaming industry such as Emotiv and NeuroSky, which has partnered with the Chinese consumer technology company Haier on a BCI smart TV. Others are also emerging and developing commercial BCI applications such as BCI neural processing software developer Mind Technologies, Geger Technologies in Austria and the Sony Corporation in Japan. The WTEC report in 2007 predicted a significant widening of future commercial demand.

BCI Human Performance, Current and Future Applications

The ultimate goal of BCI is either to restore or to enhance human performance. The bulk of current application in the United States is rehabilitative or assistive in nature, especially for individuals with "locked-in" syndromes due to disease or injury. Therefore, considerable overlap exists between Functional Electrical Stimulation applications and BCI application as outlined in figure 1.

Gerwin Schalk from the Wadsworth Center summarizes the human brain as having a wealth of computational breadth that can parallel process and convert many inputs into many outputs, however with little computational depth. In other words, it cannot process long commands of a given algorithm, and at the biological cellular level computing operates at low speeds. Computers on the other hand, have limited computational breath and can execute only few algorithms at a time, but they can execute these algorithms at very high speed.[29] As a result the powers of computers and the human brain are complimentary and the relationship is centered on the computing language. This is the premise that future systems will be able to decode, produce sounds or visual images with the same clarity as produced by our own brains. Future research will continue to develop new languages that will be mutually adopted by computer and the brain. The brain however, with its increased complexity, syntax, and taxonomy that will take longer to learn. This communication bottleneck is the fundamental impediment and can only be overcome by advanced language and interface.



(Figure 1) FES and BCI applications overlap. Reprinted from WTEC Panel Report 2007.

Current BCI Applications

Blankertz, et. al. point out that another major obstacle to advancing nonmedical application of BCI is the ability to detect accurate intentions between user and computer to control applications.[30] One area showing improvement with EEG technology is with newer electrodes, and research on “dry” electrodes that are easier to use and less time consuming to set-up is underway. There is continued development on electrodes with improved materials, better conduction, and smaller components. This coupled with miniaturization of sensors, electronics, power sources, and engineering of flexible electronics and display technologies will significantly enhance future BCI capabilities.[31]

A major impediment for advancing BCI applications is refinement of operant conditioning for subjects to learn self-control, requiring extensive individual calibration and training.   It will also be crucial to deal with the considerable variability for constant behavioral performance, and cognitive neuroscience research is underway to find neuronal correlates to explain and eventually control this variability. However, despite these noted challenges, researchers in Germany are optimistic on media and gaming applications with BCI. They are particularly focused on managing photos, video, web surfing, and music, and although in their infancy, researchers have used a web browser interface to control Google Earth via BCI.[32] BCI systems have progressed beyond the paradigm of improving communications for the disabled. They now offer measurement devices capable of assessing and decoding more brain-states in real-time, allowing for seamless measurement of workload and performance. This will further enhance analysis of the human brain state to better optimize human-machine and brain-computer interfacing.

Future BCI Applications

Researchers at the Army Research Laboratory are focused on future task-oriented BCIs for sensor technologies, artificial intelligence, and computer algorithms capable of detecting and analyzing brain data.[33] This technology would enable BCIs to detect and analyze the user's sensory environment, mood, or mental state. Increasing the bandwidth between computers and the brain will increase effectiveness of signal characterization. This enhanced signal characterization combined with non-verbal human communication such as facial expression and body language, provides insight about the operator's emotions and produces neurofeedback to potentially provide users with awareness and self-adjustment of their own brain function. Monitoring would allow for accurate, reliable detection of fatigue, attentiveness and mood which could allow for adaptation of systems or the environment.

The progression of biosensing technologies for brain imaging in the future will move away from today's traditional BCIs to augmented BCIs for everyday use.[34] Future BCIs will enable direct control of everyday objects such as lights, radio, telecommunications, computers, and so on. To achieve this level of control BCIs would need to analyze neural signals to add information beyond what could easily be obtained through manual input or other channels. As BCI technology advances, persons will be increasingly able to operate complex systems in environments that exceed the degree of freedom of our human motor systems. These advances in BCI will allow for sequential rather than parallel function that would be very applicable to aviation and space system operations. In 2008 a Human Performance report by the MITRE Corporation sponsored by the Office of the Director of Defense Research and Engineering (DDR&E) cited a DARPA call for proposals for the suitability of non-invasive BCIs for military applications, specifically in developing subconscious recognition of targets or threats.[35] Researchers at the U.S. Army Research Laboratory conclude applications in the near-term will most likely remain task-oriented. In the far-term BCIs will emerge in a holistic approach of applications that will merge brain, behavior, task, and environmental information with sophisticated sensing and computational analysis much like current cloud technology.[36] DARPA received $240 million, and the Army, Navy, and Air Force $113 million, in 2011 for cognitive neuroscience research.[37] The rate of research and computational advances will transition from task-oriented to behavior-oriented in the coming decades and will make significant advancements in mental, physical, and emotional control.

BCI Major Hurdles: Security, Social, Ethical, Moral, and Legal Issues

There will be several major challenges facing future BCI applications in the United States that will significantly limit its use. First and foremost of these challenges will be security issues. Currently the United States is engaged with countering cyber-attacks across commercial and government systems. Additionally, future BCI technology will have the ability to capture a user's cognitive activities which will likely have social, ethical and legal repercussions in Western democracies. Many countries don't share the legal constraints and ethical issues that prevent American researchers from exploring human performance improvements.

BCI Security and Privacy

The National Science Foundation has sponsored research by the University California Berkeley, the University of Oxford, and the University of Geneva that explored the feasibility of side-channel attack with BCI using low cost, commercially available BCI hardware and software. They concluded that even with today's rudimentary devices, a third-party attacker could read EEG signals and produce text and images on a screen. These researchers conducted several experiments that demonstrated that private information such as PIN numbers, area of residence, and other private information could be ascertained with high confidence. They also concluded that as the quality of devices improves, the success rate of attacks would also improve. One challenge is the fact that brain-wave signatures are user unique and therefore difficult to manipulate, but any system trained to recognize a particular user's EEG patterns could be used to extract information.[38]

As the speed of information sharing increases, and with the continued convergence of man and machine, BCI will have tremendous security and privacy implications. BCI may produce useful biometrics much like fingerprint and iris scanning but will require significant safeguards. BCI will require direct assessment of the brain in context of a computational system. This assessment will be very beneficial to add context to communication however, this will render serious privacy concerns because of the computer interface requirement. Another serious concern will be liability issues; how will accountability be assessed in regard to correct intent but incorrect detection?[39]

BCI Ethical and Legal Considerations

Future BCI will not only have an impact on individuals, but society as a whole. The prospect of BCI entertainment, neuroprostheses, online neuroresearching and marketing, and cognitive performance enhancement span a host of ethical challenges.[40] Most ethical issues for medical applications can be readily addressed, but privacy issues and "mind-reading" concerns for general users will require ethical debate. The debate over research versus treatment will likely arise, especially in the development of new technologies.[41] Future scenarios using neurofeedback to assess or control mood, emotion, fatigue, or cognitive functions may seem extremely applicable for military operations but will raise major ethical and legal issues on what the limit is on information gained, monitored or mental vulnerabilities manipulated. The right to privacy could easily be violated and new laws on privacy and consent would likely be required to address these issues. Lastly, if BCI enhancement gains in popularity limited competition will initially drive costs and limit availability to only select populations, but as research and commercialization continues this technology will become common-place.[42]

Neuroscience research is often "dual use," and BCI is no exception. State-of-the art research in BCI is being developed for warfighter performance enhancement, and future BCIs will connect to enhanced endurance exoskeletons.[43] The evolution of BCIs may eventually benefit both society and individual, but not without risks. In the military the Uniformed Code of Military Justice requires soldiers, sailors, airmen, and marines to accept medical interventions, such as immunizations and use of prophylaxis medications to render them fit for duty.[44] These issues are typically reserved for combat deployment situations, but the freedom to accept or decline what some would consider enhancements will further compound the ethical use of BCIs in military operations. Another issue with ethical and social ramifications is the use of BCI technology for deception, detection, and interrogation. Currently, EEG P300 ERPs may prove to be reliable for lie detection; however, under existing US law, using BCI technology within this realm may challenge Fourth Amendment requirements on unreasonable search and seizure.[45] Finally, Epithimios Parasidis, an Associate Professor of Law at the St. Louis University School of Law recently argued in the April 2012 *Conneticut Law Review*, that the U.S. military has committed egregious legal and ethical violations related to human enhancement and experimental research, to include human-to-computer communication.[46] He argues in his article that there are legal and regulatory shortcomings for military neuroscience research, including BCI.[47] The social, ethical and legal considerations will significantly impede BCI utilization in the United States and Western democracies. The Project BioShield Act of 2004 allows the FDA to use instrumental products in an emergency. This law was enacted to grant the Department of Defense authorization to administer Anthrax immunizations to service members.[48] Similar legislation may be necessary to enable the future BCI use by the United States Armed Forces.

BCI, Innovation Mercantilism and United States Strategy

Global innovation competition has become increasing intense. In the Winter 2011 *Issues in Science and Technology* article “Fighting Innovation Mercantilism,” author Stephen Ezell noted that the output of scientific journal papers reached historic proportions in 2009.[49] Not surprisingly, many countries have developed innovation agencies and have adopted innovation as a key component to national strategies. The 2010 United States National Security Strategy states, “To succeed, we must also ensure that America stays on the cutting edge of the science and innovation that supports our prosperity, defense, and international technological leadership.”[50] Innovation policy varies from country to country, and a positive-sum innovation strategy that adheres to international trading rules and creates an environment of innovation sharing is exceedingly rare. Today, win-win and zero-sum policies dominate the international community’s approach to innovative technologies. China is among the top zero-sum focused countries whose policies are more concentrated on mercantilism than technologic innovation. This is evident by China’s persistent control of capital, and every day it is estimated that China buys approximately US$1 billion in the currency markets to hold down the price of the Renminbi. Further, many countries have continued to evade tariff reductions, and persist with high tariffs on high-tech products and services.[51] It is not only China; the EU has resisted compliance with the World Trade Organization’s Information Technology Agreement. This innovation mercantilism can have significant security implications for technologies such as BCI, especially with the trade practices of China.

Chinese Mercantilism

There are many Chinese mercantile practices that are particularly concerning in terms of BCI technologies. As previously discussed, the Chinese are investing heavily in neuroengineering technologies. China has accumulated US$3.2 trillion in foreign exchange reserves over the last ten years. The Chinese strategy is to lead all advanced technology products and services.[52] Therefore, China's mercantilism represents a fundamental threat to the United States, and despite international commitments to economic cooperation, history reveals that meaningful global economic governance has a poor record. China is not acting alone. The future prospect exists for China, the European Union, Brazil, India, Russia, and the United States to become embroiled into a global mercantile competition with or without the involvement of other proxy nations. Innovation advantages will become increasingly more zero-sum game and competitive advantage in technology will require commitment through sound strategy.

Recommendations

Within the past decade the ability to bypass muscles and speech between a brain and a computer has become a reality.[53] The increasing research and development of BCI technology will have revolutionizing effects and will require a robust military strategy that is capable of employing, exploiting, and securing this technology across the entire spectrum of military operations or we will lag behind. BCI technology needs to be an integral component of the National Security Strategy through adequate funding, research and development, and collaborative efforts with universities and industry. The National Defense Strategy should specifically address program management and collaborative efforts between DARPA, the Services and National Laboratories, the National Science Foundation and National Institutes of Health to ensure coordinated research and development of this technology. The strategy should also address coercive and deterrent utilization of BCI technology as its utility matures for military platforms and weapons systems. Additionally, this strategy should integrate security and surveillance of BCI military information and sensory applications as an added domain within the purview of established cyber security efforts. As BCI becomes increasingly integrated into military platforms, a strategy to prepare and train airman needs to be developed. Finally, a legal strategy needs to develop to assess the ethical, privacy, social, and accountability limits of BCI.

Conclusion

BCI seemed science fiction a decade ago, but there has been an explosion of neuroscience research and development at the academic, commercial and governmental levels worldwide in the last ten years. The utilization of BCI technology will evolve from the medical and rehabilitation realm to commercial and military weapon and surveillance systems. The infusion of this technology will grant a significant competitive edge to the established observe, orient, decide, and act paradigm. Every major competitor to the United States, to include China, has recognized the strategic advantages of BCI, with strategies to actively pursue this technology. It is imperative that the United States Air Force, as the lead for cyber, space and air operations, becomes and maintains the frontrunner for employing this technology to ensure dominance in an age of expanding computing, information exchange, and movement toward an increasingly mercantile global environment by 2032. It is time for a strategy.

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