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The purpose of the study was to perform an independent assessment of current and future Soldier enhancement techniques the Army may adopt as long-term practices. These included the advances in biological, biomedical, and pharmaceutical technologies as they apply to the Army. The study team recommended the Army charter an integrated product team to conduct a one-year Human Performance Study to explore the potential of performance optimization and enhancement technologies. The team also advocated for a focused effort to develop intelligence assessments of adversary capabilities in human performance optimization and enhancement technology.

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Army Science Board
Fiscal Year 2016 Study

Army Efforts to Enhance Soldier and Team Performance

Final Report
June 2017

Department of the Army
Office of the Deputy Under Secretary of the Army
Washington, DC 20310-0103

DEPARTMENT OF THE ARMY
ARMY SCIENCE BOARD
2530 CRYSTAL DRIVE. SUITE 7098
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June 15, 2017

DUSA-ASB

MEMORANDUM FOR SECRETARY OF THE ARMY

SUBJECT: Final Report of the Army Science Board, "Army Efforts to Enhance Soldier and Team Performance"

1. I'm pleased to forward the final report of the Army Science Board (ASB) study titled "Army Efforts to Enhance Soldier and Team Performance." The study sought to assess current and future Soldier enhancement techniques the Army may adopt as long-term practices. The scope of the study included a review of potential enhancements to a Soldier's cognitive, physical, and mental performance. The study team further divided their analyses between optimization, which maximizes the Soldier's intrinsic performance, and enhancement, which expands the Soldier's intrinsic performance.

2. For this effort, the ASB brought subject matter experts in Medicine, Public Health, Chemistry, Biology, Structural Dynamics, Psychology, Political Science, and a variety of military operations and technologies, as well as former Army leaders. During its seven months together, the study team conducted over forty visits and interviews among Army and DoD agencies, Federally Funded Research and Development Centers, Academe, and commercial industry.

3. The study team made several findings and recommendations based on their work. Given the breadth of enhancement technologies and techniques, the team recommended the Army charter an IPT to conduct a one-year Human Performance Study to explore the potential of various modalities. Since adversaries are aggressively pursuing enhancement technologies, the team also recommended the Army develop an integrated intelligence assessment to track human performance optimization and enhancement technology across the globe. The team also made recommendations for Army training and performance measures, based upon advances made in understanding physical performance. The findings and recommendations were adopted by unanimous vote of the ASB on July 16, 2016.

4. I hereby endorse the findings and recommendations in this report.

James A. Tegnelia
Chairman

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EXECUTIVE SUMMARY

The Secretary of the Army tasked the Army Science Board (ASB) to conduct an "independent assessment of current and future Soldier enhancement techniques the Army may adopt as long-term practices."[1] The study team looked at advances in biological, biomedical, and pharmaceutical technologies with human enhancement potential and found several technologies in different stages of science and development that provide physical, cognitive, and psychological enhancements for Soldiers.

The study team consisted of nine ASB members and three study managers. Over the course of six months, the team visited over 40 different sites, interviewing several subject matter experts from DoD, other federal agencies, academia, commercial industry, the U.S. Olympic Team, and the U.S. Anti-Doping Agency. The study team also sought to understand the critical social, cultural, and ethical concerns regarding human optimization and human enhancement. Finally, the team reviewed and assessed the best practices and methods required to lead efforts in the various fields of enhancement.

From their work, the study team made findings and recommendations in five major areas:

1. Human Performance IPT

Finding: Soldier optimization and enhancement technologies at disparate levels of readiness for development & fielding, research, and exploration

Finding: Allocation of responsibility and authority lacks clarity and institutional buy-in

Recommendation: SA and CSA charter an IPT to conduct a one year Human Performance Study to explore the potential of these technologies.

IPT composition:

G3/5/7	OTSG / MEDCOM
G2	AMC / RDECOM
SJA	M&RA
TRADOC	ASAALT
FORSCOM	OGC

Study Tasks: recommend lead/support responsibility for:

- Policy Coordination
- R&D Program Development
- S&T Management / Integration
- Tech Watch

[1] See Terms of Reference at Appendix A.

Assess ASB human performance technology opportunities for feasibility, time frame and level of effort with respect to:

- Development & fielding
- Research
- Exploration

2. Intelligence Assessment

Finding: Our adversaries are actively pursuing Human Enhancement technologies

Recommendation: SA and CSA task Army G2 (assisted by MEDCOM & AMC) to develop a recurring, all-source, integrated intelligence assessment of global threats with respect to talent deployment, Human Performance Optimization and Enhancement technology development and deployment

3. Training Review

Finding: Soldier generations have distinct cognitive-psychological strengths and weaknesses

Finding: Man-machine teaming will be a key issue in future developments for both Soldier optimization and autonomy

Recommendation: SA and CSA task TRADOC to:

- Maintain efforts that adapt individual and collective training and education programs to leverage emerging generational cognitive-psychological advantages while mitigating their vulnerabilities
- Extend TRADOC Human Dimension effort to address man-machine teaming

4. Performance Requirements

Finding: Army common standards approach to physical training restricts ability to support individual physical optimization

Recommendation: SA and CSA task TRADOC (with assistance of G1 and MEDCOM) to extend common and MOS task-specific performance requirements beyond combat arms MOS's in order to inform individual physical optimization effort

5. Policy Development

Finding: Our adversaries may have very asymmetric perspectives on the ethical interpretations associated with the development and employment of this technology

Recommendation: SA and CSA charter Office of General Counsel, in coordination with internal and external stakeholders, to develop acceptable ethical and legal policies for development and exploitation for these technologies

1. INTRODUCTION

The U.S. Army's leadership faces a strategic inflection point regarding the implementation of human enhancement technologies. Decisions made will have far reaching implications. Enhancement technologies provide non-linear differentiators to their users, and the Army may risk ceding an overmatch position if it fails to act. Conversely, it can seize the opportunity and allow these technologies to potentially become game changers for U.S. Soldiers.

Human enhancement is happening in the Army. Many Soldiers already use supplements and pharmaceuticals to improve their performance in various ways. Army leadership may choose to ignore or passively accept the impact of self- enhancement, or it may make a deliberate effort to shape enhancement and pave the way for developing enhancement technologies that will improve mission performance. Considering that the future Army will be smaller and will encounter an operating environment that will inflict greater stress on Soldiers, the study team believes the Army should begin to leverage research and science and technology (S&T) that will help Soldiers adapt to future challenges.

Today, the Army consists of a force in which up to 20,000 (36%) of the new accessions do not complete their first term of enlistment; where 1 in 20 Soldiers fail their annual Army Physical Fitness Test (APFT); where 78,000 Soldiers are considered clinically obese (Body Mass Index >30); and where 10% of the Soldiers are diagnosed with a sleep disorder.[2] The statistics reveal an Army emerging from long years of war with a force that's become increasingly sub-optimal.

In addition, new Soldiers ("Millennials" and "Digital Natives"), have developed different neural circuitry in their brains than previous generations due to their early and prolonged exposure to digital media. This makes them good at multi-tasking, and gives them enhanced, complex reasoning and decision-making skills. On the other hand, they possess limited, deep-subject-learning abilities and diminished "people skills," including emotional aptitudes like empathy, social interaction, and teaming. These generational differences challenge the Army to determine how best to leverage the strengths, offset the weaknesses, and develop the best future Soldier.

1.1 TERMS OF REFERENCE (TOR)

To begin developing a strategy for human enhancement, the Army tasked the ASB to conduct this study under the sponsorship of the Commanding General (CG), Army Training and Doctrine Command (TRADOC). The Terms of Reference (TOR) for the study outlined three key tasks:

1. Assess the U.S. Army's current efforts associated with Soldier enhancement, and compare those efforts with other efforts occurring outside the Army

[2] The Army Surgeon General, Performance Triad: Strengthening the Health Readiness of the Total Army

2. Analyze trends in current human enhancement for relevant application to future force capabilities and consider the risks associated with their application in the military

3. Consider whether cultural and social values of foreign nations might facilitate the development and application of human enhancements that the U.S. Government may find unacceptable because of ethical, social, or moral concerns

1.2 STUDY METHODOLOGY

The study team consisted of ASB members with expertise in clinical psychology, physics, engineering, social science, and medicine. At the beginning of the discovery process, the team conducted a brief review of available literature and developed a study plan. Early on, the team determined to answer the "what?" question by defining the human domains in which enhancements could be made–physical, cognitive, and psychological–which the team defined as follows:

- Physical – relating to the body, including the brain, but other than the mind

- Cognitive – intelligence (fluid and crystalized), executive functions (e.g. attention, mental flexibility, executive cognitive control, response inhibition, decision making, problem solving, motivation, impulsivity, etc.), memory, language, motor functioning, perception, visuospatial skills, insight, and judgment

- Psychological – emotions (emotional regulation), attachment, personality hardiness, grit, motivational factors, resilience, adaptability, maturity, empathy, impulsivity, risk taking, frustration tolerance, leadership, flexibility, and social interactions

The study team then asked the "how?" question and categorized the possible means of enhancing performance as follows:

- Pharmacological – drugs, hormones, and other new molecules

- Biological – the means to change the human structurally (e.g., cellular modification)

- Technological - instruments that use hardware, software, or some combination (e.g., electrical or magnetic stimulators of the brain)

- Education and training

Finally, the study team adopted the technical use of two terms to further clarify what enhancement entails, to distinguish that from current, more common practices that many Soldiers undertake voluntarily to boost their performance in various ways, and to delineate a "how much?" question regarding the depth and/or level of modification:

- Optimization – maximizing the intrinsic performance
- Enhancement – expanding the maximum intrinsic performance

Following the establishment of these key terms, the study team embarked on a more comprehensive review of the literature and began a very aggressive schedule of visits and interviews across the country. The team made over 40 visits, interviewing Army, Air Force, Navy, DoD, and U.S. Government agencies, representatives from academia and industry, and subject matter experts from the U.S. Olympic Committee and the U.S. Anti-Doping Agency.

The scope of the study aligned with the TOR tasks and included visits and a review of the literature to allow the team to better understand the critical role of social, cultural, and ethical influences on human optimization and human enhancement. The study team also established a line of inquiry during selected visits to examine options for the Army to address these concerns when adopting optimization and enhancement regimens for Soldiers.

Once the study team determined its formal findings, it identified current S&T with the potential to optimize and/or enhance Soldier performance. The team then analyzed available technologies in terms of the affected human domain (physical, cognitive, and psychological), the relative technological maturity, and the anticipated development time (short-, mid-, or long-term). The team also considered existing social, cultural, and ethical influences. Finally, the team identified challenges a Soldier enhancement implementation plan would likely encounter if the Army followed that path.

Based upon this work, the team developed recommendations for consideration by the Secretary of the Army and the Chief of Staff of the Army. The ASB voted to adopt the findings and recommendations at its Summer plenary session in July 2016.

2. THE PHYSICAL DOMAIN

Most of today's research efforts deal with physical optimization techniques such as physical training, nutrition, and supplements. The Army has been successful at improving the physical readiness of the force by instituting a few minimum standards for individual physical training (PT) and capability. Unfortunately, minimum standards don't necessarily encourage individual Soldier optimization, and except for a few specialized areas (e.g., Special Operations, Military Police, etc.) and cases where the minimum standards aren't met (e.g., APFT failure), individual Soldiers aren't mandated to pursue optimization.

The goal of enhancement is to augment human capabilities beyond intrinsic capability, beyond optimization, and into optimal performance capacity. Enhancements can occur via exoskeletons, pharmaceuticals, skeletal-muscle mitochondrial biogenesis, tissue regeneration technology, and gene-editing. Certain medical advances designed to rehabilitate an ill or injured person can be extended and applied to optimize and/or enhance a Soldier. These techniques may provide advantages on the battlefield and in other hostile environments.

2.1 OPTIMIZATION IN THE PHYSICAL DOMAIN

The gap between the Army's minimum PT standards and an individual's physical optimization reflects an absence of processes to assess or to promote optimization based on the individual Soldier's potential. It also reflects the Army's industrial model approach to personnel management, currently under review and revision in favor of an approach geared more toward talent management (TM). A basic tenet of TM calls for the promotion of individual strengths, the development of specific traits, and the view that each Soldier has a unique mix of capabilities and experiences that must be addressed discretely. The process of physical optimization should follow that same tenet.

2.1.1 EVOLVING ARMY PT REQUIREMENTS

The Army made a positive step in better defining PT requirements when it established gender neutral standards for combat arms military occupational specialties (MOS). While developing these standards, the Army conducted a detailed study of the physical tasks required for the combat arms MOS and determined the minimum physical requirements to accomplish those tasks. Thus, the standards were closely linked to what a Soldier would physically do for his or her job. The Army has also moved toward developing PT for Soldiers similar to the manner in which athletes train for events.

The development of job-specific standards and subsequent data collection will create a baseline for the assessment and promotion of individual physical optimization. For example, the study team searched for the best technology to optimize physical performance, traveling to well-known centers such as the Auburn University School of Kinesiology, University of Pittsburg Neuromuscular Research Laboratory, U.S. Olympic Team Training Center, and the Special Warfare Education Group (Airborne) at Fort Bragg, NC. Consensus among the experts calls for a clear understanding of the required task to achieve optimization, whether that task is throwing a football, swinging a golf club, running long distances, or firing a rifle. Standard practices to understand the task involve using cameras in conjunction with movement and torque sensors to capture data while a subject repeatedly performs a task. Follow on assessments of the performance inform how best to train for that individual optimization. The bulk of the assessment effort is completed before the individual training begins.

While the technology required to perform this kind of assessment is becoming much less expensive, the Army will also need personnel with experience in exercise physiology as well as experts in each MOS (with a deep understanding of the tasks and how to break the tasks down into discrete steps). Once these elements are in place, the Army will be well-positioned to take the next steps in developing individualized assessments and training strategies on a large scale, beyond the combat arms MOS.

2.1.2 INDIVIDUAL NUTRITION (EDUCATION, BEHAVIOR MODIFICATION, DIETARY ACCESS)

Proper nutrition is as critical as PT to achieve optimization. The study team observed techniques at the U.S. Olympic Team Training Center and at the Special Warfare Education Group (Airborne) that used a baseline nutrition assessment to supplement the PT program.

As with individualized PT, the Army would need to scale the guidance provided by nutrition specialists, but because eating is such a fundamental aspect of the human condition (i.e., everyone knows how to do it, has well-developed preferences, etc.), adopting a highly specified nutrition regimen would also require support in the form of training and education, with the possibility of extending into behavior modification. Furthermore, the Soldier's success with targeted nutrition will be successful only if the Soldier has access to the required nutrients and food. Thus, the Army will need to survey the food landscape on its posts to ensure enterprise support for this form of optimization. Having the proper food readily available and in the right environment to reinforce proper behavior is critical.

2.2 ENHANCEMENT IN THE PHYSICAL DOMAIN

Promising technologies that enhance physical performance exist at different phases of development: five years (short term), between five and ten years (midterm), and ten plus (long term). The convergence of technologies may speed development of some of these enhancements.

"If we can carry faster and farther, guess what we can do at the end? We can fight better."

Soldier, 82nd Airborne

2.2.1 EXOSKELETONS

Exoskeletons are wearable, mobile machines designed to allow limb movement while increasing speed, strength, and/or endurance. The military has been working on exoskeleton technology since the 1960s.[3] Recent advances and ongoing developments in electronics and material science will enable U.S. Soldiers to run faster, carry heavier weapons, and leap over obstacles on the battlefield. Future exoskeletons may also be able to shield Soldiers from the effects of bullets and bombs.

Exoskeletons can be used in one of two ways: the first is to offset the metabolic burden of tasks such as those related to dismounted operations; the second use is to enable heavy lifting by an individual, such as that required in trans-boarding shipments during tactical operations. Several companies have mature prototypes for military applications and exoskeletons are also currently used in industry (Fig. 2.1).

Figure 2.1. Examples of Exoskeletons

[3] Dollar and Herr 2008

Hugh Herr, PhD., head of the Biomechatronics research group at the MIT Media Lab, developed a prototype exoskeleton designed to offset the metabolic burden during dismounted operations (Fig. 2.1, upper left). The model is light-weight and has efficient electric motors. Research is focused on further improving the efficiency and torque of the electric motors and making them smaller and more efficient, which would reduce overall weight and energy requirements.

UC-Berkley's BLEEX exoskeleton (Fig. 2.1, upper right) is lightweight, reusable, decreases the Soldier's metabolic burden during dismounted operations, enhances maneuverability, and currently resides in the budget authority (BA) prototype stage 6.3-6.4. Although expensive and battery-operated, the cost may decrease with advancements in enhanced battery-efficiency. A Soldier using BLEEX can lift items weighing up to 2,240 lbs., allowing for the replacement of medium to heavy motorized equipment required to move payload, supplies, and materiel. That capability would provide a measure of relief to the logistics requirements in an expeditionary environment. It also allows for the rapid deployment of forces into hostile or semi-hostile environments while establishing overmatch capability, and enhances the ability to conduct operations immediately upon arrival.

A similar type of exoskeleton developed by Sarcos, now a subsidiary of Raytheon, allows humans to perform heavy lifting operations. Sarcos developed their model with DARPA funding and they have mature prototypes available.

The study team observed a robust effort by industry and research institutions advancing various types of exoskeletons. These efforts have produced multiple prototypes that can be used by the Army for field experimentation.

2.2.2 PHARMACOLOGICAL AGENTS

Stories of athletes using steroids are familiar, as are the warnings of detrimental health effects that arise from the unregulated use of steroids. Perhaps a lesser known fact is that Soldiers all over the world also use steroids and other pharmacological agents to enhance their physical performance.

For example, a multitude of new drugs that have been developed to counter genetic metabolic defects may be used to enhance human performance. The anabolic steroid oxymetholone increases the amount of the chemical erythropoietin, which leads to an increase in the production of erythrocytes. It's prescribed to patients suffering from sarcopenia (the loss of muscle due to aging) who need to improve muscle mass, strength, and growth.[4] It's also prescribed to patients who are anemic, undergoing chemotherapy, or who suffer from other blood disorders, because of the drug's ability to increase oxygen-carrying capacity. Oxymetholone is relatively safe when taken short term. Generally, long term use of most

[4] Supasyndh 2013

anabolic steroids produces several untoward side effects (addiction, mental disorders, liver damage, etc.), and most use is banned, outright, by major sports leagues.

Current illicit use among some Soldiers includes buying steroids from China. Of course, the best course of action would be to place individuals under the care of a physician to monitor the use and effects of steroids and other pharmaceuticals. Thus, if pharmaceuticals are to be used safely for performance enhancement, the Army will need to develop new policy.

2.2.3 SKELETAL MUSCLE MITOCHONDRIAL BIOGENESIS

A multitude of drugs counter rare, genetic diseases that affect mitochondrial biogenesis[5] and skeletal muscle performance.[6] Repeated endurance-based exercises combined with periods of rest lead to different gene products that result in muscles with improved fatigue resistance. This improvement is proportional to mitochondrial density and mitochondrial enzyme activity, (i.e., it's proportional to mitochondrial biogenesis). Hence, Soldiers who engage in the exercise routines will see improvements in their strength endurance profile. Even Soldiers who don't exercise may see an overall improvement in their physical performance when they use these drugs.

Several studies have been conducted to assess the effectiveness of training programs in reducing musculoskeletal injuries. The Eagle Tactical Athlete Program (ETAP), specifically developed for the 101st Airborne Division to reduce musculoskeletal injuries, has been shown to optimize performance and to reduce injuries by modifying musculoskeletal characteristics needed for this reduction.[7] ETAP is effective for reducing all unintentional injuries and stress fractures.

2.2.4 TISSUE REGENERATION TECHNOLOGY

The Army made a long-term investment in the Armed Forces Institute for Regenerative Medicine (AFIRM). AFIRM is developing regenerative medicine technologies as treatment options for severely wounded servicemen and women. The intent is to improve patient function by regenerating muscle, bone, skin, and other organs. The effort may also produce technology that enhances physical performance by using newly discovered tissue signaling necessary for muscle regeneration, or by the implantation of new muscle or bone tissue.

2.2.5 GENE-EDITING TO ENGINEER HUMAN BEINGS

Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) technology is a gene-editing tool derived from the process bacteria use to protect themselves from viruses. The

[5] The growth and division of pre-existing mitochondria, or more technically, the process by which mitochondria increase their ability to make adenosine triphosphate by synthesizing additional respiratory enzyme complexes.

[6] Thevis, 2015

[7] Sell, 2016

bacterium detects viral DNA, constructs complementary RNA, binds to the nuclease Cas-9, and destroys the viral DNA. When applied to humans, CRISPR technology has the potential to cut DNA that is producing deleterious gene products and replacing those sequences with normal or improved DNA. It can also be used to create transgenic animals. By opening the process of cutting and splicing DNA sequences, CRISPR has advanced the understanding of how genes work, how we might eliminate mutations that cause disease, and how editing can change the physical nature of living creatures. Though human applications are more long-term (i.e. 10+ years away), the growth in research activity related to this technology places some aspects in the short-term range (Fig. 2.2).[8] It should also be noted that other countries (China and Great Britain) are advancing this technology in humans and opening the potential for a multitude of enhancements. The United States and allies must decide whether and how research should proceed to match, mitigate, or counter these advances.

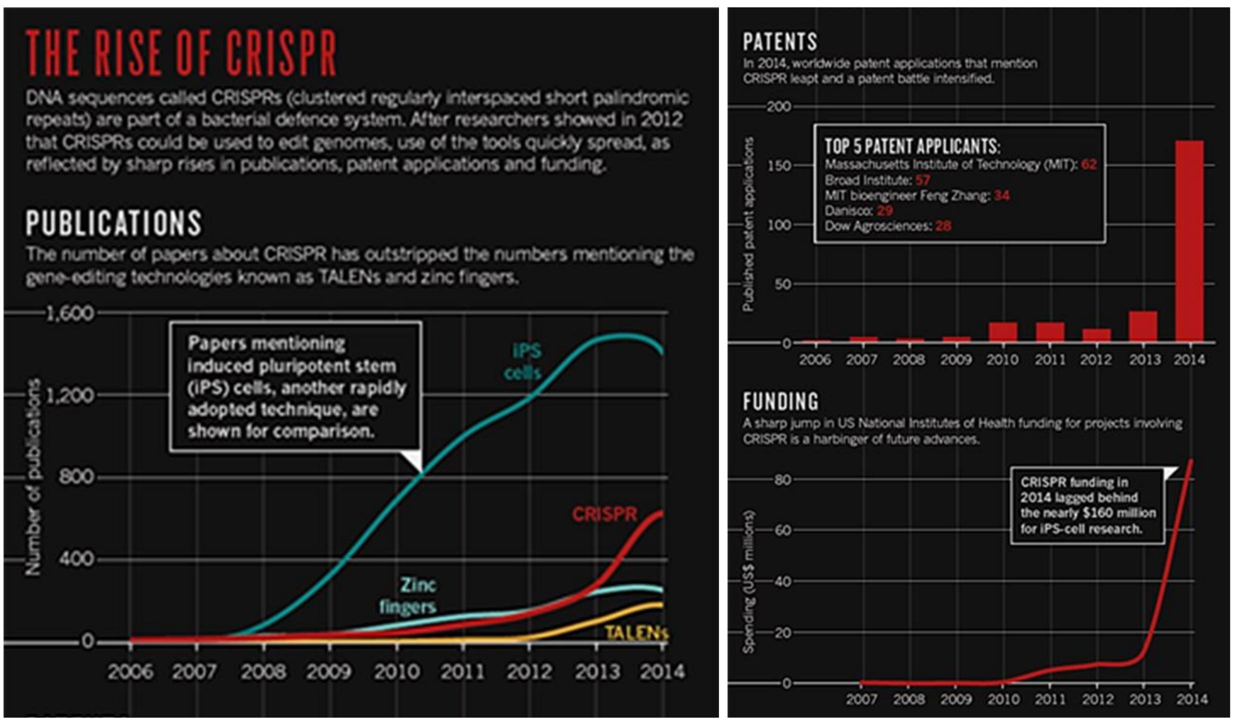

Figure 2.2 CRISPR Technology

[8] Ledford 2015

3. COGNITIVE DOMAIN

The cognitive domain encompasses all the aspects of intelligence, executive functions (e.g., attention, mental flexibility, executive cognitive control, response inhibition, decision making, problem solving, motivation, impulsivity, etc.), memory, language, motor functioning, perception, visuospatial skills, insight, and judgment. Two terms important to this domain require further definition: "fluid" and "crystalized" intelligence, which were first described by Raymond Cattel. Fluid intelligence is the ability to reason and to solve new problems, regardless of prior experience or knowledge. It includes the ability to successfully solve truly unknown problems, problems like the ones Soldiers face and will continue to face in combat almost every day. Crystalized intelligence is the ability to use prior knowledge, skills, and experience, and it employs the depth and breadth of knowledge and the ability to reason.

During the last decade, the scientific understanding of how human cognition works has been expanding exponentially, and that rate of growth is expected to continue over the next two decades. Progress in this area will prove critical to the development of new interventions designed to mitigate conditions like Traumatic Brain Injury (TBI) and Post-Traumatic Stress Syndrome (PTSD). The progress will also be critical to the development of interventions geared toward optimizing or enhancing human cognition.

Some key technologies enabling the increased understanding of how the brain works include new neuro-imaging techniques like Functional Magnetic Resonance Imaging (fMRI) that identifies brain activity based on neuronal metabolism, optogenetics which uses light to study genetically modified neurons that highlight neuronal function and interactions, and evolving techniques that overlay neural signaling molecules like serotonin release and removal on a fMRI.[9]

Collaborative research efforts will also accelerate the science and understanding of the brain, such as the Presidential Brain Initiative, which funds a large effort to better understand brain function and is expected to present results in the next ten years.

The fields of genetics, epigenetics, and microbiome science will likely contribute new interventions that will lead to optimizations and enhancements in human cognition. Research intended to ameliorate genetic disorders will shed light on how better to screen or even edit the human genome to prevent diseases and other unwanted conditions. Epigenetics explores how environmental factors (e.g., nutrition) affect the expression of genes, and by extension, how they may play a role in the development of traits that enable cognitive capabilities. The human microbiome is responsible for the production of over 80% of the body's serotonin and dopamine, two key neuro-signaling molecules, but we have yet to fully understand the process or its ramifications, such as the microbiome-brain interaction.

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[9] Interview with Alan Jasanoff 29 March 2016, MIT

Finally, work in psychology, education, simulation technology, artificial intelligence (AI), computer-brain interaction, and pharmaceuticals also present opportunities to optimize and enhance human cognition.

Work in the aforementioned areas also present complications. For instance, we now know that the human pre-frontal region is not fully formed until the mid-twenties. Cognitive executive functions are carried out in this brain region but there is no clear understanding of what this late development means to the Soldiers or the Army. Given that most Army recruits are young, and their pre-fontal region is not fully developed, more research is needed to fully understand the implications.

The "holy grail" of cognition is the ability to enhance fluid intelligence. Fluid intelligence is critical for Soldiers facing a de novo event during operations for which they have no previous knowledge or experience. The study team found the scientific community divided on this issue: most scientists believe, and have data to demonstrate, that fluid intelligence ability is genetically driven (i.e., once formed, it cannot be changed). Other scientists believe fluid intelligence abilities are changeable, and they're pursuing new research to demonstrate how. Aside from this debate, there's overwhelming evidence that all other aspects of cognition (e.g., crystalized intelligence, memory, executive functions, etc.) can change. Thus, there are several potential avenues to optimize and enhance Soldier cognition.

3.1 OPTIMIZATION IN THE COGNITIVE DOMAIN

The study team identified the following techniques and technologies that show promise for enabling developments in optimizing cognition.

3.1.1 RETOOLED EDUCATIONAL PROCESSES AND EDUCATORS

As previously discussed, new Soldiers, as Millennials and Digital Natives, have different cognitive strengths and weaknesses. The Army must follow the lead of educational institutions and come around to the understanding that it can't continue to use the teaching methods of previous generations. There's an opportunity to revise the curriculum to leverage the cognitive strengths of the new generation and to improve on their weaknesses. For the new curriculum to work, it will require retooling the educators.

3.1.2 ADAPTIVE LEARNING

Computerized systems tailor individual learning experiences. The pace of learning is dictated by previous knowledge and the individual's ability to learn the material. One goal is to make learning more effective by changing the learning process from a passive to an active experience.

3.1.3 MINDFULNESS TRAINING

An individual is taught to bring his or her awareness to the present moment through the practice of meditation and other techniques. The practice is easy to learn and has widespread use in professional sports, industry, and some elite military units. Mindfulness training has a well-documented improvement in attention, focus, and executive function.

3.1.4 COGNITIVE EXERCISES

Designed to increase the ability to learn new information, understand relationships, and to develop plans or conclusions, there's some discrepancy on the usefulness of the methodology. The study team believes it's worthwhile to further explore the benefits of the approach to gauge whether Soldiers' cognitive performances may be optimized.

3.1.5 ASSIMILATION LEARNING

The study team observed incredible advances in the development of augmented and virtual reality, avatars, and simulator technologies, both in education and the gaming industry. The Army, the Navy, and the Air Force have made substantial investments to develop new applications using assimilation learning technology. The following technologies may be applied to optimize Soldier performance:

3.1.5.1 AUGMENTED AND VIRTUAL REALITY FOR SIMULATION

Augmented and virtual reality simulators facilitate the learning process. The study team observed successful applications using clear competences (training goals) and clear tasks and outcome measures. Lacking these, it's very hard to design the right simulation and difficult to determine if the simulation accomplishes the anticipated goal. Advancements in computer power and in hardware will make augmented reality the simulation of choice because it's less expensive, and it provides more freedom to use it in different environments. For example, the HoloLens is a head mounted standalone computer developed by Microsoft that will bring freedom of movement with the computing power required for augmented reality simulation.

3.1.5.2 AVATARS

Computer generated actors are used for role-playing, tutoring, coaching/mentoring, and entertainment. The Institute of Creative Technology developed very successful applications in social interaction and negotiating skills using avatars. Avatars and related applications haven't been widely used by the Army, and there's a good opportunity to start. Current applications called intelligent tutors integrate avatars and adaptive learning to achieve individualized earning experiences that can be extremely useful in Army training and education.

3.1.6 DECISION SUPPORT ARTIFICIAL INTELLIGENCE

The field of artificial intelligence in growing at an exponential rate fueled by the development of advanced computer power and software. Decision support applications provide promise to augment military missions. For example, the Air Force Research Laboratory at Wright Patterson Air Force Base is developing a decision support application for perimeter defense. An Airman responsible for perimeter defense uses drones, robots, and sensors to respond to an intrusion alarm. As the Airman executes the response, decision support AI computes second and third order effects from the actions. The AI tool presents its analyses in a manner that facilitates manipulation and execution by the operator. For example, with a simple click on the display, the Airman may re-deploy sensors or drones to cover an unseen gap in security created by the initial response. Other examples of applications where AI may optimize human cognition lie in command support and expert medical decision making.

3.1.7 OPTIMIZATION OF MAN-MACHINE TEAMING

Machines (robots, drones, etc.) are going to play a larger role in the future of warfare, but little research has been done on how to optimize the man-machine interaction. The main issues relating to this interaction deal with trust and communication. As the machine systems become more autonomous, there will need to be direct and clear communication between the machine and the Soldier. If the machine moves autonomously, it needs to tell the Soldier that it's doing so and explain why. Failure to do so will decreases the Soldier's trust in the machine. In addition, the man-machine communication must be simple and reliable. The Soldier must believe that the machine's behavior is reliable and predictable. All these aspects of man-machine teaming will offer an opportunity to optimize the relationship but will require extensive multidisciplinary research.

3.1.8 CONVERGENCE OF ASSIMILATION AND ARTIFICIAL INTELLIGENCE TECHNOLOGY

As the assimilation and AI technologies mature, opportunities will emerge to integrate both into applications designed to optimize human cognition. For example, the Army might explore development of a maximally distributed, micro-footprint operations center. Some of today's staff functions can be done by AI systems remotely while a dispersed staff use assimilation technology to observe and interact with a common operational picture. Commanders would have real time, realistic terrain and force overlays that would automatically update as the operation evolves, facilitating the staff work and the command decision process.

3.2 ENHANCEMENT IN THE COGNITIVE DOMAIN

The study team found the following promising technologies for cognition enhancement.

3.2.1 PHARMACOLOGICAL AGENTS

The Army has been using repurposed drugs to enhance human cognition for many years. Caffeine and amphetamines are the most common, both used to ameliorate the effects of fatigue and lack of sleep. Other drugs on the market today and in the clinical development pipeline can be repurposed from specific medical conditions and applied to cognition enhancement, especially in the areas of memory and executive function improvement. For example, Ritalin (methylphenidate) is a central nervous system stimulant used to treat Attention Deficit Hyperactivity Disorder (ADHD), but some college students use it to improve alertness and memory. Drugs developed to treat Alzheimer's may also enhance memory in normal subjects. Drugs that affect dopamine and noradrenaline in the brain may enhance executive functions. Further research will be required to assure the desired effects using repurposed drugs don't come at the cost of the health and/or safety of subjects using them.

3.2.2 BRAIN STIMULATION

As of now, the human brain can be stimulated using electrical, magnetic, and ultrasound stimulation. The oldest technology is transdermal electrical stimulation. Stimulation applied to specific areas of the brain may result in activating or deactivating that brain area, resulting in enhanced or reduced cognition. For the technology to be fully useful, a better understanding of how the brain works will be required, providing clear brain targets for stimulation. For example, current research, such as the Brain Initiative at MIT, seeks to identify areas of the brain responsible for the assimilation of discrete memories. Using imaging techniques, investigators are identifying whether an area of the brain responsible for the assimilation is active (on) or inactive (off). This kind of experimentation will help in the brain functional mapping process and will advance the science by identifying targets for stimulation. The clinical and the enhancement potential for this technology is unlimited. The study team observed one example involving experimentation with electrical stimulation targeted at the frontal lobe to minimize the effects of sleep deprivation. Caution must be exercised using these technologies, however, because while they may enhance a brain function, they may also have a detrimental effect on other functions.

3.2.3 INTRA-CORTICAL MICROSTIMULATION

Because the cranium provides insulation for the brain, the best method for directing efficient electrical stimulation requires a device in direct contact with the brain. DARPA is expanding the use of direct cortical macrostimulation to restore subjects' vision or hearing. The concept has been validated, and the goal now is to implant a device in the cranium to enable direct contact with the cortex. If such a device proves feasible, it may have benefits beyond restoration of lost vision or hearing, including an opportunity to expand vision to the whole visual spectrum and/or to expand the hearing to the whole sound spectrum. The device would also provide an efficient brain-machine interface.

3.2.4 INTRACRANIAL STIMULATION

Another method to stimulate an area of the brain uses direct electrical stimulation with a probe. This more invasive procedure is currently used with mixed results in the treatment of incurable mental disease, especially severe, intractable depression. The technique is the most effective way to stimulate deep areas of the brain and may prove critical to treat clinical conditions. As other technologies develop and brain science advances, the technique may also develop to provide cognitive enhancement.

3.2.5 GENE EDITING

Technology is available allowing scientists to explore gene modification. Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) technology can be used to modify human embryos with the aim of preventing known genetic defects. In the future, this technology can be used to modify the human genome to enhance cognition, or other desirable traits. CRSPR technology is relatively inexpensive and easy to use, so it’s likely to become widespread. Science needs to develop around which genes code for specific aspects of cognition. The effort is underway to make these discoveries, and viable targets for editing may be available in the next 10-20 years.

3.2.6 COMPUTER-BRAIN INTERFACE

The ultimate way to enhance human cognition is to enhance cognitive ability with a computer. The idea is that the computer has access to brain information and will seamlessly aid with memory, problem solving, executive functions, etc. While this may sound like science fiction, there are multiple efforts around the world working to solve the technical issues. For example, work on the brain-computer physical interface, and on understanding how the brain processes data–the brain is not a binary system like computers–is well underway. As this information becomes available in the next 20 years, the ultimate computer-brain interface may become a reality.

4. PSYCHOLOGICAL DOMAIN

The psychological domain comprises a range of emotional, social, and personality functions such as emotional regulation, attachment, personality hardiness, grit, motivation, resilience, adaptability, maturity, empathy, impulsivity, risk taking, frustration tolerance, leadership, flexibility, and social interaction. Psychological variables are complex, multifactorial, overlapping with the cognitive and physical (brain) domains, and are subject to individual differences.

4.1 OPTIMIZATION IN THE PSYCHOLOGICAL DOMAIN

As defined for this study, optimization of psychological functioning involves processes aimed at maximizing the intrinsic psychological performance capacity and level. The study team found S&T in this area are promising and can reach maturation within the short- (0-5 years) and mid- (5-10 years) terms. Five approaches to optimizing psychological functioning in military members are of interest.

4.1.1 MINDFULNESS TRAINING

Mindfulness is related to Buddhist practices of meditation. Mindfulness training, originally developed by Jon Kabat-Zinn in 1990, is an intervention or practice that has been well researched in recent years.[10] There's convincing empirical evidence that mindfulness changes brain functioning. Mindfulness has also been shown to affect functional connectivity, neuroplasticity, and both grey and white matter.[11]

Elizabeth Stanley at Georgetown University developed Mindfulness-based Mind Fitness Training ("M-Fit" or "MMFT") which involves an eight-week course and twelve minutes of mindfulness practice per day. The Marine Corps has been using M-Fit since 2012 to improve "mental performance,"[12] reporting that Marines found they slept better and felt more relaxed after receiving mindfulness training. Researchers suspect that mindfulness training would also help with situational awareness and better emotion regulation.

Researchers have found that mindfulness decreased activity in the right anterior insula and the anterior cingulate cortex of infantry Marines when exposed to aversive interoceptive cues following twenty hours of mindfulness training.[13] The authors suggested that decreasing aversive interoceptive cues may improve resilience. A review of studies examining the effects of mindfulness on psychological health concluded that mindfulness decreases subjective distress and increases a sense of well-being, decreases emotional reactivity, and improves one's ability to regulate one's own behavior.[14] There's also some suggestion that mindfulness may influence

[10] Keng, Smoski, & Robins, 2011; Watford & Stafford, 2015
[11] Tang & Posner, 2013
[12] http://www.washingtontimes.com/news/2012/dec/5/marines-expanding-use-of-meditation-training/
[13] Haase, Thom, Shukla, Davenport, Simmons, Stanley, & ... Johnson, 2016
[14] Keng, Smoski, & Robins, 2011

gene-environment interactions.[15] One study found that eight weeks (twenty hours) of mindfulness training prior to deployment might modify the resilience mechanisms in Marines, as evidenced on a variety of physiological and psychological measures.[16] Additional research provided promising signs that mindfulness training would prove an effective optimization for Soldiers:

- Practiced as a technique, it can affect both cognition and emotion regulation.[17]
- Training may be accomplished with good effect sizes in a relatively short amount of time, e.g., in as little as twelve hours.[18]
- Training participants can achieve a state of mindfulness with just a fifteen-minute intervention.[19]
- Military recruits can use mindfulness and self-compassion to decrease excessive worry resulting in less impulsive behavior.[20]
- Mindfulness training can decrease lapses of attention in military members. [21]

Additional complementary and alternative medicine approaches, such as iRest© Yoga Nidra practices, have been piloted with military members. iRest© is a guided mindfulness mediation practice intended to reduce stress, anxiety, and worry, while promoting peace, joy, and wellbeing. A feasibility study with veterans experiencing post-traumatic stress disorder found participants reported increased self-awareness, better emotional regulation, and a greater sense of relaxation in just eight weeks of training.[22] Further research is needed to determine if these approaches have protective effects and if they can optimize or enhance psychological performance.

Mindfulness and meditation approaches are non-invasive, carry minimal risks, and are cost effective interventions that can be implemented relatively easily and quickly. Effectiveness and feasibility of mindfulness with military members has been empirically validated. Given the amount of research conducted, the study team believes the Army could employ mindfulness training immediately.

4.1.2 SLEEP

The deleterious effects of sleep deprivation are unequivocal. The task is not necessarily to increase the amount of sleep military members get, though that may be preferable when possible, but to optimize the restorative effects of the sleep they do get.

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[15] Posner, 2007
[16] Johnson, Thom, Stanley, Haase, Simmons, Shih, & ... Paulus, 2014
[17] Opialla, Lutz, Scherpiet, Hittmeyer, Jäncke, Rufer, & ... Brühl, 2015
[18] Carmody & Baer, 2009
[19] Watford and Stafford, 2015; p. 101
[20] Mantzios, 2013
[21] Jha, Morrison, Dainer-Best, Parker, Rostrup, and Stanley (2015)
[22] Stankovic, 2011

Sleep assessment tools help Soldiers and their leadership observe and measure indicators of the Soldiers' fatigue level, quality of sleep, and potential impact on functioning. Emerging technology has been empirically validated to assess fatigue (including information related to the individual's circadian rhythms, sleep cycles, and reaction time) to schedule workers, in this case military members, to perform their tasks optimally. One example of such technology is the Fatigue Avoidance Scheduling Tool (FAST®), developed by the Air Force because fatigue is a major human factor concern in aviation.[23] The Navy started to use this technology several years after it was developed to help schedule pilots in a manner that optimized their sleep-rest rhythms. Another tool, "2B Alert," developed and empirically validated at the US Army Medical Research and Materiel Command, is a mobile app which provides data specific to the individual regarding his or her responses to fatigue and sleep and the effect on cognitive performance.[24] The technology involves the use of an algorithm that predicts current and future states of cognitive alertness to optimize functioning.[25]

OMEGA-3

There's somewhat equivocal evidence regarding the impact of omega-3 on cognitive and psychological functioning. A pilot study of military members found that although there were no neurocognitive or psychological effects of omega 3, there was an effect of omega 3 decreasing daytime drowsiness. An expert panel concluded, with a high consensus, that increasing the intake of omega-3 would be beneficial to the warfighter.

4.1.3 NUTRITION

Optimal nutrition for the warfighter is necessary for physical, cognitive, and psychological functioning. Using nutritional supplements to enhance functioning may be a practical, reasonable cost, and minimal risk intervention that could be used by military members to maintain and possibly enhance functioning.[26] In a 2013 study, the Defense Science Board (DSB) suggested that there are numerous areas related to warfighter nutrition that warrant further evaluation and potential implementation, such as better understanding of the metabolism of the warfighter and how it might be optimized, of neuroplasticity and resilience, and of the microbiome and the relationship between gut health and cognitive and emotional functioning.[27] Some researchers maintain that more uniformed dietitians will need to be deployed in theatre to manage programs if nutritional interventions are to be effective.[28] As research on nutritional supplements matures, combat dietitians will have a better understanding of what the optimal dose of the supplements would need to be in order to produce an effect.

4.1.4 STRESS RECOGNITION TOOLS

Identifying the subtle signs of increased stress early on can provide Soldiers and their leadership with an opportunity to intervene and mitigate to optimize performance. Stress

[23] Eddy, Moise, Miller, & Welch, 2009
[24] Ramakrishnan, Khitrov, Liu, & Relfman, 2015
[25] http://techlinkcenter.org/summaries/2b-alert-personalized-alertness-and-cognitive-performance-app
[26] Such as the findings on Omega-3 (in box) by Dretsch, Johnston, Bradley, MacRae, Deuster, and Harris, 2014. The expert panel cited was reported by Coulter, 2014.
[27] Defense Science Board, "Technology and Innovation Enablers for Superiority in 2030;" p. 55
[28] Deuster, 2014

recognitions tools are very useful in this regard because individuals may tend to habituate to stress and may not notice that they are experiencing stress. A variety of physiological metrics such as galvanic skin response, increased glucocorticoids, and increased blood pressure are indicative of the stress response. Affective computing[29] is a technology that “recognizes, interprets, and synthesizes emotions.”[30] Although more technological and scientific work is required, there may be some promise of this technology to optimize Soldiers’ abilities to become more aware of their emotional responses and to be better able to interpret these responses, allowing them to make better decisions when experiencing stress.

4.1.5 PSYCHOLOGY OF MAN-MACHINE TEAMING

The advancement of technology used on the battlefield has created a need to understand and to manage the dynamic between the Soldier and the machines he or she operates. Trust is a perquisite to effective man-machine teaming.[31] Building trust between a Soldier and a robot is an emerging area of study requiring more exploration. “Ensuring appropriate levels of trust can be a particular challenge to the successful integration of robotic assets in human teams.”[32] Robots can augment or optimize human functioning, but the Soldier must have a fair amount of confidence in the robot’s performance before he or she will take chances with the machine on the battlefield.[33] A Soldier may be better able to trust a robot if he or she understands the decision-making process of the robot, especially with a “low ability robot,”[34] because of the transparency gained through understanding its rationale. Along that line, the DSB reported:

> What is needed now is to field a more comprehensive human-machine collaboration capability system, where the physical and mental states of the operator are fed back into the weapon system, making the human a more seamless part of the overall system. This would allow adaptive automation to more effectively support individual warfighter cognitive capabilities in real-time and improve sociotechnical team performance through a mission.[35]

4.2 ENHANCEMENT IN THE PSYCHOLOGICAL DOMAIN

As defined for this study, enhancement includes processes used to expand the maximum intrinsic performance capacity and level of each Soldier, allowing the individual to achieve new capabilities. The study team identified four categories of promising enhancement technologies: (1) pharmacological agents; (2) noninvasive brain stimulation; (3) invasive deep-brain stimulation; and (4) gene-line editing. Assuming investments in each of these research areas

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[29] Piccard, 1997
[30] As cited in Truong, Neerincx, & van Leeuwen, 2008, p. 170
[31] Billings, Schaefer, Kocsis, Barrera, Cook, Ferrer, Hancock, & Chen, 2012
[32] Freedy et al., 2007, as cited in Pynadath & Hill, 2015, p. 2
[33] Billings, Schaefer, Kocsis, Barrera, Cook, Ferrer, Hancock, & Chen, 2012
[34] Pynadath and Hill, 2015
[35] DSB 2013 p. 52

continues, the study team assessed S&T maturity in these areas within the short- (0-5 years), mid- (5-10 years), and long- (10-20 years) terms.

Enhancement technologies in the psychological domain have the potential to assist the individual with emotional regulation, attachment, and personality traits and expression (e.g., hardiness, grit, resilience, motivation, maturity, adaptability, empathy, impulsivity, risk-tasking, frustration tolerance, leadership, flexibility and social interactions). The study team noted that evaluation will need to be conducted on the risk of detrimental impact to the unit's performance (Squad up to Corps) when individual Soldiers receive some form of enhancement. In other words, how will the group dynamic be affected?

4.2.1 PHARMACOLOGICAL AGENTS

In the broadest sense, pharmacological agents are generally defined as biologically active substances prescribed by an authorized healthcare provider for therapeutic effects on human tissues or organs with the goal to restore the body and/or mind to a pre-existing norm.[36] To meet the requirements set out in the TOR, the study team also considered the non-therapeutic[37] use of pharmacological agents (i.e., the use of biologically active agents in either supervised or unsupervised modes to achieve an effect above and beyond the individual's respective norm). In previous studies, biologically active agents of different types have been referred to as subclasses of nutraceuticals,[38] dietary supplements (DS)[39] and/or banned substances,[40,41] with the intent of either maintaining wellness and/or the potential for producing enhancements.

Previous studies have shown that multiple types of people (e.g., armed forces personnel,[42] college students, athletes) self-elect to use biologically active agents to achieve psychological enhancement for a variety of reasons. Common examples include, but are not limited to, the prescribed pharmacological agents Ritalin (methylphenidate) and Inderal (propanolol).

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[36] Pharmacological definition. *Merriam Webster Online Dictionary*. Retrieved from Merriam Webster Online Dictionary http://www.merriam-webster.com/dictionary/pharmacological.

[37] Therapeutic definition. *Merriam Webster Online Dictionary*. Retrieved from Merriam Webster Online Dictionary http://www.merriam-webster.com/dictionary/therapeutic.

[38] Jonas, W.B. (2014) Nutritional Armor: Dietary Supplements in the Military. Retrieved from http://www.nutraingredients-usa.com/Research/Nutritional-Armor-Dietary-Supplements-in-the-Military.

[39] Austin, K.G., Farina, E.K., & Lieberman, H.R. (2016), Self-reported side-effects associated with use of dietary supplements in an armed forces population, *Drug Test. Analysis, 8,* 287–295. Retrieved from www.drugtestinganalysis.com. DOI 10.1002/dta.1905.

[40] Thevis, M., Kuuranne, T., Walpurgis, K., Geyer, H., & Schänzer, W. (Wiley Online Library 2016) Annual banned-substance review: analytical approaches in human sports drug testing, *Drug Test. Analysis*. Retrieved from www.drugtestinganalysis.com. DOI 10.1002/dta.1928.

[41] World Anti-Doping Agency Website. (Sept. 29, 2015). *WADA January 2016 Prohibited List*. Retrieved from https://www.wada-ama.org/en/media/news/2015-09/wada-publishes-2016-prohibited-list.

[42] J.J. Knapik, R. A. Steelman, S.S. Hoedebecke, E.K. Farina, K.G. Austin, & H.R. Lieberman. (2014). A systematic review and meta-analysis on the prevalence of dietary supplement use by military personnel. *B.M.C. Complement. Altern. Med.*, *14*, 143. DOI: 10.1186/1472-6882-14-143.

Propanolol was developed as a beta-blocker therapeutic to treat hypertension, but is now in unregulated use as an "off-label" intervention for suppressing anxiety, and has the potential to serve as an amnesiac against the formation of disturbing memories from a traumatic event, such as those observed with post-traumatic stress disorder (PTSD), while preserving the ability to recall details of the event. Studies to assess the capacity of propanolol as a psychological enhancer have produced varied results. A meta-analysis review of prior studies conducted by Canadian and U.S. researchers in 2013[43] concluded that propanolol may be effective in reducing the negative emotional experiences associated with the recall of traumatic experiences. However, a more recent meta-analyses review published in 2016 by researchers in the Netherlands concluded:

> No statistically significant differences between the efficacy of propranolol and benzodiazepines regarding the short-term treatment of panic disorder with or without agoraphobia. Also, no evidence was found for effects of propranolol on PTSD symptom severity through inhibition of memory reconsolidation. In conclusion, the quality of evidence for the efficacy of propranolol at present is insufficient to support the routine use of propranolol in the treatment of any of the anxiety disorders.[44]

Ultimately, additional evidence-based research would be required to determine the efficacy of propanolol as a psychological enhancement method for use by military personnel.

Methylphenidate is typically prescribed for ADHD, but now is typically seen in unregulated use for potentially increasing attention span and learning capacity. Studies are limited in the case of prescription stimulants in terms of their potential for increasing attention span and learning capacity. However, the potential health risks[45] of unregulated use is perceived to be much higher, requiring additional research and analyses to assess any potential for psychological enhancement relative to the potential health dangers associated with long-term use.

4.2.2 NONINVASIVE BRAIN STIMULATION

For the purposes of this study, noninvasive brain stimulation (NiBS) is defined as a transcranial electric stimulation (tES) procedure employing electrical, magnetic, or ultrasonic phenomena to stimulate the brain's neural networks for potential neuropsychiatric benefits, without requiring

[43] Lonergan, M.H., Lening, B.A., Olivera-Figueroa, A., Pitman, R.K. & Brunet, A. (2013). Propranolol's effects on the consolidation and reconsolidation of long-term emotional memory in healthy participants: a meta-analysis, *J Psychiatry Neurosci*, *38*(4), 222-231.

[44] Steenen, S.A., van Wijk, A.J., van der Heijden, G. JMG., van Westrhenen, R., de Lange, J. & de Jongh, A., (2016) Propranolol for the treatment of anxiety disorders: Systematic review and meta-analysis, *Journal of Psychopharmacology, 30*(2) 128–139.

[45] Lakhan, S. E. & Kirchgessner, A. (2012). Prescription stimulants in individuals with and without attention deficit hyperactivity disorder: misuse, cognitive impact, and adverse effects. *Brain and Behavior*, *2*(5): 661–677. DOI: 10.1002/brb3.78.

the implantation of electrodes into the brain that could permanently damage the nervous tissue. Two forms of electrotherapy, transcranial direct current stimulation (tDCS), and transcranial alternating current stimulation (tACS)[46,47] are used in research and clinical practice to stimulate neural activity with low electrical current applied via external electrodes attached to the scalp. Working on similar principles to stimulate neuromuscular tissue, the transcranial magnetic stimulation (TMS)[48,49] method employs a pulsed magnetic field to induce an electrical field within the brain transmitted by a magnetic coil attached to the scalp.

Research on all three NiBS methods has occurred for several decades, with results showing that each tES method is capable of exciting or inhibiting brain activity based on numerous factors including, but not limited to: configuration and placement of cathode and anode electrodes; pulse duration, magnitude, frequency, number, and overall duration of applications; which part of the brain is being targeted; patient's state of consciousness; and the patient's unique physiology. The underlying intention is to modulate the human brain's rhythmic activity, affecting behavior and resulting in potential neuroplastic changes to the brain's sensory, motor, and higher cognitive processes. Prior history has shown that the tDCS and TMS methods are most commonly used as research and therapeutic tools, but progress continues with tACS,[50] tDCS, and TMS techniques.[51]

Previous safety concerns about NiBS techniques centered on potential risk of biological tissue breakdown and permanent disruption of full brain function. Test protocols in use today are considered relatively safe due to the use of low currents, limited duration, and pulsed application, although headaches and/or some skin sensation may be experienced during the treatment, and thereafter, the potential exists for mild skin irritation at the sites of electrode applications.[52] Generally, tDCS is less expensive and easier to use than TMS, yet TMS is believed to be safer. Each method has been used with the potential to improve psychological targets (e.g. depression, sleep deprivation, and ADHD). To date, the greater drawbacks of both types of methods are the limited ability to spatially target key areas of the brain, lack of deep brain

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[46] Brunoni, A.B., Valiengo, L., Baccaro, A.; Zanão, T.A., de Oliveira, J.F., Goulart, A.; Boggio, P.S., Lotufo, P.A., Benseñor, I.S., & Fregni, F. (2013). The Sertraline vs Electrical Current Therapy for Treating Depression Clinical Study: *the Results* From a Factorial, Randomized, Controlled Trial. *JAMA Psychiatry, 70*(4), 383-391. DOI:10.1001/2013.jamapsychiatry.32.

[47] Sanguinetti, J.L., Smith, E., Allen, J.J.B., & Hameroff, S. (2014, December) Chapter 32 Human Brain Stimulation with Transcranial Ultrasound Potential Applications for Mental Health. *Bioelectromagnetic and Subtle Energy Medicine*, 2nd ed., Boca Raton, FL: CRC Press.

[48] Rachid, F. (n.d.) "What is TMS?", *Dr Fady Rachid's Transcranial Magnetic Stimulation (TMS) web page*. Retrieved from http://www.tmsdrrachid.com/whatistms.html.

[49] Sliwinska, M.W., Vitello, S., & Devlin, J.T. (2014). Transcranial Magnetic Stimulation for Investigating Causal Brain-behavioral Relationships and their Time Course. *J. Vis. Exp.* , *89*, 1-9, e51735. DOI:10.3791/51735.

[50] Herrman, C. S. , Rach, S., Neuling, T. , & Strüber, D. (2013.) Transcranial alternating current stimulation: a review of the underlying mechanism, and modulation of cognitive processes. *Frontiers in Human Neuroscience,* 7(Article 279) 1-13.

[51] Saiote, C., Turi, Z., Paulus, W. & Antal, A. (2013.) Combining functional magnetic resonance imaging with transcranial electrical stimulation. *Frontiers in Human Neuroscience,* 7(Article 435) 1-7.

[52] Linder Center of Hope. (n.d.) *TMS Pros and Cons.* Retrieved from Linder Center of Hope website http://lindnercenterofhope.org/patients-families/treatments-programs/ect-and-tms/tms-pros-and-cons/.

stimulation capabilities, and the limited number of promising results seen in therapeutic cases. Thus, researchers have worked to improve the focality of tDCS and to create a set-up for high-definition tDCS.[19]

Low frequency ultrasonic methods, known as transcranial ultrasound (TUS),[13,53] rely on transmitting ultrasound waves through the skull and tissue to influence brain activity. The advantage that TUS has over the tDCS and TMS methods is that the ultrasonic beam can be focused to target key areas, including deep brain structures, with millimeter precision. Ultrasonic methods have been used as both therapeutic and imaging tools at low and high intensities. High intensities are generally employed to destroy biological tissue, such as kidney stones, through localized heating and cavitation. Lower intensities are generally used for diagnostic imaging of anatomical structures (e.g. checking for evidence of deep vein thrombosis and blood clots in legs). Low intensity TUS methods can also be used to stimulate high neuron activity, thus the potential as a new and beneficial neurotherapeutic treatment alternative to tDCS and TMS. TUS is a relatively nascent science requiring more research to fully assess potential safety concerns and to enhance understanding of the efficacy of the method.

4.2.3 INVASIVE DEEP BRAIN STIMULATION

Invasive deep brain stimulation (DBS) techniques require surgical implantation of a device, such as an electrode in the brain, connected by leads to an implantable pulse generator (IPG), which is a microcontroller similar to a pacemaker and typically placed under the patient's collarbone. Electrical pulses are delivered with millimeter precision to key brain areas to stimulate neural networks. Though precise electrical stimulation of the brain is achieved with this method with the potential for neuropsychiatric benefits,[54,55] it's the least desirable of the stimulation approaches because of the complexity and invasiveness of the surgical technique, which increase the potential for other side effects.

[53] Tyler, W.J., Tufail, Y. , Finsterwald, M., Tauchmann, M.L., Olson, E.J. , & Majestic, C., (2008). Remote Excitation of Neuronal Circuits Using Low Intensity, Low-Frequency Ultrasound. *PLoS ONE, 3* (10), e3511.

[54] Fisher, c. E. (2014, january). Psychiatrists embrace deep-brain stimulation: brain-stimulation procedures for psychiatric disorders are on the rise. Should we be concerned? *Scientific american*. Retrieved from http://www.scientificamerican.com/article/psychiatrists-embrace-deep-brain-stimulation/.

[55] Selimbeyoglu, A. , & Parvizi, J. (2010.) Electrical Stimulation of the human brain: Perceptual and behavioral phenomena reported in the old and new literature. *Frontiers in Human Neuroscience, 4* (Article 46) 1-11.

The application of DBS has been limited to more extreme cases[56] related to depression,[57,58,59,60] FDA approved neurosurgery for neuromuscular disorders such as Parkinson's,[61] dystonia,[62] and epilepsy.[63] In pilot trials for therapeutic treatment of Alzheimer's,[64] the technique is used in cases that haven't responded well to other traditional therapeutic practices. Results show that DBS techniques hold significant promise in providing psychological enhancements for a variety of neuropsychiatric conditions, yet some test results have also been inconclusive on the success of treatment for various conditions.

Additional research needs to be completed to fully assess the safety and efficacy of implementing DBS practice on a wider basis for psychological enhancements. National (federal and private) and internationally-funded DBS research studies and randomized trials have been in progress for several years and continue within military and private sectors.

4.2.4 GENE-LINE EDITING / GENE TRANSFER

Gene-line editing, also referred to as gene transfer, is defined by the National Institutes of Health's (NIH) National Human Genome Research Institute (NHGRI) as:

> A relatively new possibility for the treatment of rare genetic disorders and common multifactorial diseases by changing the expression of a person's genes. Typically, gene transfer involves using a vector such as a virus to deliver a therapeutic gene to the appropriate target cells. The technique, which is still in its infancy and is not yet

[56] Lozano, A. (2013, January). Parkinson's, depression and the switch that might turn them off. TEDxCaltech. Retrieved from http://www.ted.com/talks/andres_lozano_parkinson_s_depression_and_the_switch_that_might_turn_them_off.

[57] wrobel, s. (2015, spring). Flipping the switch: targeting depression's neural circuitry. *Emory medicine magazine.* Retrieved from emorymedicinemagazine.emory.edu/issues/2015/spring/features/brain-hacking/flipping-the-switch/index.html.

[58] gupta, s., & segal, a. (2012, april). Treating depression with electrodes inside the brain. CNN. Retrieved from http://www.cnn.com/2012/04/14/health/battery-powered-brain/

[59] Schlaepfer, T.E., Bewernick, B.H., Kayser, S., Hurlemann, R., & Coenen, V.A. (2014). Review Deep Brain Stimulation of the Human Reward System for Major Depression—Rationale, Outcomes and Outlook. *Neuropsychopharmacology 39*, 1303–1314.

[60] Morishita, T., Fayad., S.M., Higuchi, M., Nestor, K.A. & Foote, K.D. (2014). Deep Brain Stimulation for Treatment-resistant Depression: Systematic Review of Clinical Outcomes. *Neurotherapeutics, 11,* 475-484.

[61] National Institutes of Health (NIH), National Institute of Neurological Disorders and Stroke (NINDS). (n.d.) *What is Deep Brain Stimulation for Parkinson's Disease?* Retrieved from NIH NINDS website. http://www.ninds.nih.gov/disorders/deep_brain_stimulation/deep_brain_stimulation.htm

[62] Loftus, M. (2015, Spring). Capping the overflow: Easing dystonia symptoms, *Emory Medicine Magazine.* Retrieved from http://emorymedicinemagazine.emory.edu/issues/2015/spring/features/brain-hacking/capping-the-overflow/index.html.

[63] Eastman, q. (2015, spring). Calming the storm, reducing epileptic seizures. *Emory medicine magazine.* Retrieved from emorymedicinemagazine.emory.edu/issues/2015/spring/features/brain-hacking/calming-the-storm/index.html

[64] Dotinga, R. (2014, May). Brain Stimulation Shows Promise Against Alzheimer's: German pilot study found four of six patients kept, improved their memories one year later, *HealthDay Reporter.* Retrieved from WebMd website. http://www.webmd.com/alzheimers/news/20140506/brain-stimulation-shows-early-promise-against-alzheimers.

> available outside clinical trials, was originally envisaged as a treatment of monogenic disorders, but the majority of trials now involve the treatment of cancer, infectious diseases and vascular disease. Human gene transfer raises several important ethical issues, in particular the potential use of genetic therapies for genetic enhancement and the potential impact of germline gene transfer on future generations.[65]

One naturally occurring system, first developed in 1993, [66] has gained widespread attention over the last 5 years.[67] Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) and CRISPR-associated protein 9 (Cas9) sequences allow organisms to innately adapt and develop immunity to invading genetic material.[68] The relative user-friendly nature of the nuclease makes it a prime candidate for genome editing and adaptation. Since the initial demonstration of CRISRP/Cas9 system in 2012, researchers have successfully used the system and variants to target a wide-array of genes in many organisms. Others have induced single-point mutations, gene deletions, and in some cases, rearrangements. CRISPR/Cas9 research continues to grow rapidly due to the relative simplicity of working with the genomic system. The potential for gene editing options may be unlimited, including the option for potential psychological enhancement, yet additional research is required to evaluate potential genetic targets that would provide the most benefit from modification.

The study team noted there will likely be differences between the U.S. and other nations regarding the types of gene therapy that will be considered as acceptable (politically, ethically, culturally, etc.) therapeutic procedures and pursued in wider practice.[69]

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[65] Hanna, K.E., (2006, March). Germline Gene Transfer. *National Institutes of Health (NIH): National Human Genome Research Institute (NHGRI).* Retrieved from the NIH: NHGRI website https://www.genome.gov/10004764/germline-gene-transfer/.

[66] Abbott, a. (2016, april). The quiet revolutionary: how the co-discovery of crispr explosively changed emmanuelle charpentier's life. *Nature: international weekly journal of science.* Retrieved from nature website www.nature.com/news/the-quiet-revolutionary-how-the-co-discovery-of-crispr-explosively-changed-emmanuelle-charpentier-s-life-1.19814.

[67] Lander, E.S. (2016, January). The Heroes of CRISPR. *Cell, 164.* Broad Institute of MIT and Harvard, Department of Systems Biology, Harvard Medical School, Boston, MA. Retrieved from http://dx.doi.org/10.1016/j.cell.2015.12.041.

[68] Reis, A., Hornblower, B., Robb, B., & Tzertzinis, G., (2014). CRISPR/Cas9 and Targeted Genome Editing: A New Era in Molecular Biology, *New England Bio Labs, Inc. Expressions I*. Retrieved from NEB, Inc. website https://www.neb.com/tools-and-resources/feature-articles/crispr-cas9-and-targeted-genome-editing-a-new-era-in-molecular-biology.

[69] Griffiths, J. (2016, July). "Chinese scientists to conduct first ever human gene editing trial." CNN Health website. Retrieved from http://www.cnn.com/2016/07/21/health/chinese-scientists-human-gene-crispr-cas9/

5. ETHICAL, CULTURAL AND LEGAL CONSIDERATIONS

New technologies used in warfare tend to raise ethical concerns. The use of nuclear weapons and the weaponization of nuclear power, biological and chemical agents, and unmanned vehicles are recent examples. Emerging technologies in stem cell research, genetics, neuroscience, robotics, and big data are the next likely candidates to raise ethical and legal questions. As the issues are resolved, they will shape rules of engagement (ROE), public opinion, and international laws. Hence, it's not technological development alone that determines how these technologies will be employed on the battlefield. As it develops concepts of operation for new combat technologies, DoD also need to lead the discussion and development of ethical understanding around the employment of these technologies.

5.1 THE NEGATIVE IMPACT OF NEW TECHNOLOGY

Recent history demonstrates the employment of new combat technologies without any deliberate, prior, public discourse can have detrimental effects on public opinion and international relations. Three examples illustrate the potential for negative outcomes:

1. U.S. military and CIA use of unmanned aerial vehicles (UAV) has raised significant public outcry and debate.[70] ISR coverage from UAVs allowed U.S. forces to establish patterns of life, conduct reconnaissance of high threat areas, and gain entrance into areas exposed to chemical, biological, radiological, and nuclear dangers. When the CIA and DoD began to arm the UAVs, questions of combat ethics arose over the UAVs' ability to strike from standoff distance with no risk to the operators stationed hundreds or thousands of miles away. To U.S. adversaries, UAVs simply represent cowardice, a sentiment that may have aggravated contempt, which is counterproductive to any U.S. strategy in the Middle East, as adversaries may have leveraged that narrative to recruit more combatants. Beyond the propaganda, allied nations have raised concerns that the use of unmanned vehicles represents disregard for other nation's sovereignty, airspace, and borders. In other words, it represents U.S. arrogance and audacity.

2. The use of cyber technologies to intercept Internet communication in the U.S. and abroad by the National Security Association led to accusations of domestic spying and public trust eroded. Moreover, relations with Allies were damaged when it was revealed that the U.S. had intercepted the German Chancellor's phone communications. These and other revelations embarrassed the U.S. at the international level.

3. The issuing of administering performance-enhancing drugs to Soldiers to prolong their natural wakeful and alert states began in World War II when the US Army issued amphetamines.[71] Studies after the war reported adverse effects of long-term use, such as impaired judgment and dangerous risk-taking behaviors. Withdrawal symptoms also

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[70] Dave Shunk, "Ethics and the Enhanced Soldier of the Near Future," *Military Review,* Jan-Feb 2015, pp 91-98.

[71] Patrick Lin, "More Than Human? Ethics of Biologically Enhancing Soldiers," *The Atlantic.com*, 16 February 2012.

consisted of mental fatigue, depression, anxiety, and suicidal thoughts. High-dose caffeine and modafinil have also been administered to enhance Soldiers' performance.

These cases illustrate the necessity to understand cultural, ethical, and legal issues, as well as the branch and chain sequence effects that accompany any implementation of new technology.

5.2 FRAMING DISCUSSION ON SOLDIER ENHANCEMENT

DoD and the Army have already invested in human enhancement, but the agencies have yet to develop thoughtful and informed strategies on addressing the cultural, ethical, and legal concerns that these technologies will raise. A consistent line of inquiry during the study team's data gathering process included questions on the legal, ethical and cultural matters and concerns of practitioners in the scientific and technological fields. While there were no consistent approaches to these issues beyond traditional institutional review boards, common themes emerged around the consent of Soldiers receiving enhancement, the duration of the effects of enhancement, and clarity on any detrimental side effects.

The most comprehensive approach to addressing concerns about Soldier enhancement was articulated by members of the Institute for Ethics and Emerging Technologies (IEET) at California Polytechnic State University, San Luis Obispo. Researchers at IEET examined the legal, operational, and ethical implications of human enhancement.[72] The study team believes Army leaders could use IEET's examination to help frame the Army's own efforts in addressing the issues around Soldier enhancement. To that end, the study team took a brief look at these issues.

5.2.1 LEGAL CONSIDERATIONS

Certain enhancements may arguably turn Soldiers into weapons, and are therefore subject to both international and domestic legal restrictions and oversight. International laws of relevance include The Hague and Geneva Conventions, the Biological and Toxin Weapons Convention, the Chemical Weapons Convention, and the Rome Statute of the International Criminal Court. Should the Army determine some enhancements do, in fact, weaponize the Soldier, it's more likely that these international laws will apply. The level of regulation of enhanced warfighters would depend upon the enhancement technology (robotics, nanotechnology, and biomedical, etc.) and the degree of enhancement. Historically new weapons must conform to certain guidelines:

- Use allows for discrimination by the operator between combatants and non-combatants.
- Use must be proportional to the military objective and keep noncombatant casualty to a minimum.

[72] Patrick Lin, Maxwell J. Mehlman, and Keith Abney, *Enhanced Warfighters: Risk, Ethics, and Policy,* January 2013.

- The weapon's method of attack must be minimally harmful to achieve military objective and not harm combatant more than necessary.

Since the operator and weapon will be one and the same, it's reasonable to believe enhancement would be found to comply with the first two tenets, so long as Soldiers continue to receive training in the laws of armed conflict, rules of engagement, etc. The ability to adhere to the third tenet may be easier than with a traditional weapons system, since it should be easier for Soldiers to attenuate themselves to a given situation than it would be for them to change settings on a weapon system.

Soldier enhancement also raises questions of legal authority, requirement, and consent. In the past, the U.S. military wrestled with these issues with its vaccination program. The Army has established both precedence and lessons learned for managing these issues, most recently from the mandated anthrax vaccine. The Anthrax Vaccine Immunization Program was established in 1997 and received criticism from both military and civilian medical personnel. Nonetheless, any Soldier who refuses the vaccine could be court-martialed under the Uniform Code of Military Justice for disobeying a direct order.

Other laws and regulations are in place to protect Soldiers from abusive practices. For example, Executive Order 13139 requires the Secretary of Defense to obtain informed consent from service members before administering investigational drugs or "off-label" drugs (a drug used for something other than its approved or intended use). The President can waive this requirement if obtaining individual consent isn't feasible or would run counter to the best interest of the member or to national security. DoD Directive 6200.2, Use of Investigational New Drugs for Force Health Protection, has similar guidelines regarding investigational drugs. The Army will have to conduct a thorough legal review to determine the viability of enhancements and whether and how it may administer enhancements (i.e., mandatory, voluntary, etc.).

5.2.2 OPERATIONAL CONSIDERATIONS

Soldier enhancement will likely have significant operational implications related to unit cohesion, command relations, and performance evaluation.

Returning to the example of the military vaccination program, it's both economical and/or best practice to administer vaccines to all Soldiers. Many of the vaccines protect against communicable diseases, and a mandatory program ensures optimal effectiveness and provides the best chance for mission success. Moreover, vaccines are inexpensive, and the program isn't cost prohibitive to administer widely.

In contrast, there's no compelling reason yet to enhance all Soldiers, and some enhancement technology may be cost-prohibitive. Consequently, enhancement technology may be limited to a subset of Soldiers or may be phased-in. In either case, the Army would create two (or more) populations of Soldiers, based on their levels of enhancement.

The Army needs to plan for this eventuality and prepare to manage complications resulting from the asymmetry that will occur by creating a subset of Soldiers who are more capable—physically, mentally, and/or emotionally—than Soldiers who haven't been enhanced. At the unit level, this may lead to friction among team members and may adversely affect unit cohesion. Historically, the military has been relatively successful with integrating Soldiers of different races, religions, genders, and sexual orientations. In this case, there will be a division deliberately created by the institution, based on capability (or other factors) because enhanced Soldiers will be designed to be better (i.e., more capable). Without a set policy, individual commanders may incite and/or exacerbate friction between the "types" of Soldiers. For example, enhanced Soldiers may be assigned different mission sets, spared from the menial tasks (to better capitalize on the Army's investment), held back from dangerous missions (to protect the investment), etc. Without careful attention from senior leadership on how to maintain unit cohesion, the differences in capabilities may lead to a sense of entitlement on the part of enhanced Soldiers and resentment on the part of unenhanced Soldiers.

Enhancement could also affect the relationships between Soldiers and commanders. The command relationship might be described as an agreement between commanders and their subordinates whereby the commander defines strategy and mission goals, and subordinates operationalize the strategy and accomplish the mission. Subordinates don't typically challenge their commander unless they view their mission as somehow illegitimate, or the commander as incompetent or incapacitated. If subordinates are enhanced and commanders aren't, the disparity may foster misunderstanding and mistrust. Commanders who haven't experienced the benefits of enhancement may over- or underestimate capabilities gained by their subordinates, which could lead to frustration and dissent among the enhanced Soldiers.

While enhancement promises the potential for significant gains in capability, there's also the potential for negative side-effects. The Army will need to consider how best to incentivize and reward Soldiers who opt-in for enhancement. Hazardous or special duty pay programs may serve as good models.

For all that the Army is likely to invest in enhancing its Soldiers, it will need to develop accurate assessments of its return on investment. Evaluating enhanced Soldiers using existing criteria wouldn't likely provide accurate assessments. Performance evaluation and promotion criteria will also have to be adjusted for enhanced Soldiers, as they'll have advantages over their unenhanced peers, and a system that doesn't take the differences into account will likely be perceived as unfair.

5.2.3 ETHICAL CONSIDERATIONS

Many of the issues noted so far have ethical entanglements beyond the legal and operational concerns. The IEET model provides a framework that the Army could adopt to systematically consider the ethical implications of enhancement. Assessments prior to implementation and development would keep practice within ethical bounds and avoid unnecessary harm to Soldiers and society at large. Some principles the Army should follow include:

- Soldier enhancement must only be undertaken for legitimate military goals.
- The use of enhancement must also be necessary to achieve the objective. If there are no alternatives to achieving the military goal, then enhancement may be appropriate.
- The benefit of enhancement must be greater than the risks or harm to the Soldiers and noncombatants. The concept of proportionality is central to military ethics.
- The enhancement should not sacrifice the soldier's integrity and humanity. Diminishing a Soldier's dignity for the sake of enhancement will erode the core character of the Soldier.
- The burden that the enhancement imposes on the Soldier should be minimized during service and after service. If reversibility of enhancement will achieve that, then research and development activities need to include reversibility.
- Informed consent is an important aspect that DoD needs to consider carefully. Can informed consent be truly obtained in a military command structure? When, if ever, is it ethical to waive informed consent to achieve military goals?
- Transparency of the S&T behind enhancement development and public explanation of its necessity may reduce public outcry. If transparency to the public jeopardizes national security, then a civilian oversight group can be established, like an institutional review board.
- DoD and the Army need to determine the most ethical protocol to determining who receives enhancement and who doesn't.

The potential impact of Soldier enhancement on society must be examined and understood by the Army. Soldiers eventually return to a civilian life. Any uncertainties around enhancement programs will be multiplied a thousand-fold when enhanced Soldiers leave the Army. The cost and benefit of either removing the enhancement from Soldiers before returning them to civilian life or leaving them enhanced must be considered and fully understood. Depending on the specificities of enhancement, e.g., the invasiveness, how widespread the implementation, etc., a complete reversal or removal may be too costly or onerous. The Army will need to develop plans for such cases to determine how Soldiers will re-adapt to civilian life.

History has shown that the most challenging military problems aren't the ones that have technological solutions. The scientific community has demonstrated time and again that technological answers can be developed. The more challenging military problems have been related to ethical issues. Thus, it will be essential that the military and the public engage and consider the numerous issues around Soldier enhancement before and during development. Engaging in these discussions after the technology has arrived would likely lead to a backlash by society and possible setbacks to an enhancement program that would otherwise keep Soldiers on par with adversaries.

6. CURRENT ARMY RESEARCH ON HUMAN ENHANCEMENT AND OPTIMIZATION

The Army's current research efforts are focused primarily on Soldier optimization. U.S. Army Medical Research and Materiel Command (USAMRMC), and the Natick Soldier Research Development and Engineering Center (NSRDEC) perform the bulk of that research, while the Chief Scientist at the Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASA/ALT) oversees programs and policies. During this study, the study team found no focused research efforts on Soldier enhancement in the Army.

Most technologies for human enhancement are being developed for specific medical treatments and will need Food and Drug Administration (FDA) approval before they can be used in human trials. As of today, USMRMC is conducting much of the research that promises to lead to enhancement solutions. However, USMRMC conducts the research for clinical reasons, and not with the potential for enhancement as a goal. For example, current research in tissue regeneration, traumatic brain injury, and post-traumatic stress syndrome research will provide solutions that can have a secondary use for enhancement. USMRMC works with the FDA and conducts clinical trials on humans following regulations that govern institutional review boards, informed consent, etc., and it's the only Army command with the clinical and FDA expertise to advance the enhancement research. However, USAMRMC may be legally constrained in leading Soldier enhancement efforts due to medical ethical considerations. The issue requires further investigation.

NRSDEC has a soldier optimization and enhancement research program, the most relevant being the Soldier and Squad Performance Optimization (S2PO) along with cognition research work. NRSDEC does not have clinical or FDA experience, but they have extensive experience with human subject protection.

To advance both Soldier optimization and enhancement efforts, it will be critical to identify an organization or office capable of integrating very complex research. The study team identified ASAALT (Science Officer), USAMRMC, and NSRDEC as current stakeholders in such an endeavor.

Some promising technologies, such as CRISRP and gene editing, may not be adopted by the U.S. Army for legal and ethical considerations. That reluctance won't stop adversaries from advancing those technologies and finding military applications. To guard against losing advantage in human capital, the Army should develop a Technical Watch function to monitor such advances. This would exist separately from any optimization and enhancement research programs, but would complement those programs where possible. Given the technical nature of the subject, only a handful of organizations in DOD can perform the Technical Watch, and the study team was not able to identify an organization in the U.S. Army with such a mission in the Soldier enchantment space.

7. FINDINGS AND RECOMMENDATIONS

7.1 HUMAN PERFORMANCE IPT

Finding: Soldier optimization and enhancement technologies at disparate levels of readiness for development & fielding, research, and exploration

Finding: Allocation of responsibility and authority lacks clarity and institutional buy-in

Recommendation: SA and CSA charter an IPT to conduct a one-year Human Performance Study to explore the potential of these technologies.

IPT composition:

G3/5/7	OTSG / MEDCOM
G2	AMC / RDECOM
SJA	M&RA
TRADOC	ASAALT
FORSCOM	OGC

Study Tasks: recommend lead/support responsibility for:

- Policy Coordination
- R&D Program Development
- S&T Management / Integration
- Tech Watch

Assess ASB human performance technology opportunities for feasibility, time frame and level of effort with respect to:

- Development & fielding
- Research
- Exploration

7.2 INTELLIGENCE ASSESSMENT

Finding: Our adversaries are actively pursuing Human Enhancement technologies

Recommendation: SA and CSA task Army G2 (assisted by MEDCOM & AMC) to develop a recurring, all-source, integrated intelligence assessment of global threats with respect to talent deployment, Human Performance Optimization and Enhancement technology development and deployment

7.3 TRAINING REVIEW

Finding: Soldier generations have distinct cognitive-psychological strengths and weaknesses

Finding: Man-machine teaming will be a key issue in future developments for both Soldier optimization and autonomy

Recommendation: SA and CSA task TRADOC to:

- Maintain efforts that adapt individual and collective training and education programs to leverage emerging generational cognitive-psychological advantages while mitigating their vulnerabilities
- Extend TRADOC Human Dimension effort to address man-machine teaming

7.4 PERFORMANCE REQUIREMENTS

Finding: Army common standards approach to physical training restricts ability to support individual physical optimization

Recommendation: SA and CSA task TRADOC (with assistance of G1 and MEDCOM) to extend common and MOS task-specific performance requirements beyond combat arms MOS's in order to inform individual physical optimization effort

7.5 POLICY DEVELOPMENT

Finding: Our adversaries may have very asymmetric perspectives on the ethical interpretations associated with the development and employment of this technology

Recommendation: SA and CSA charter Office of General Counsel, in coordination with internal and external stakeholders, to develop acceptable ethical and legal policies for development and exploitation for these technologies

APPENDIX A – TERMS OF REFERENCE

SECRETARY OF THE ARMY
WASHINGTON
JAN 0 4 2016

Dr. James Tegnelia
Chairman, Army Science Board
101 Army Pentagon
Washington, DC 20310

Dear Dr. Tegnelia:

I request the Army Science Board (ASB) conduct a study entitled "Army Efforts to Enhance Soldier and Team Performance." The object of the study is to perform an independent assessment of current and future Soldier enhancement techniques the Army may adopt as long-term practices. This study will look at the advances in biological, biomedical, and pharmaceutical technologies as they apply to the Army.

U.S. Army Soldiers and teams operate in complex battle spaces facing diverse and austere environments, challenges posed by rapid advancements in technologies available to the adversary, and a dynamic space in which to leverage human relations. As the Army evolves to fielding smaller, more dispersed formations connected via networked situational awareness, it needs to be cognizant of the increasing demands it levies upon its individual Soldiers. These tactical complexities demand improved cognitive, physical, and mental capabilities, as well as increased physical, technical, and cultural aptitudes from each Soldier, in every mission.

In order to successfully meet future mission requirements, the Army must examine potential enhancements to a Soldier's cognitive, physical, and mental performance. This study will assess the Army's current efforts associated with Soldier enhancement, and compare those to efforts occurring outside the Army. The study will also analyze trends in the broader area of human enhancement for relevant application to future force capabilities, and consider individual, organizational, and cultural risks of application within the military. Finally, the study should consider whether and how cultural values of foreign nations may facilitate the development and application of enhancements that the U.S. Government would see as more extreme or unethical.

This study defines Soldier enhancements as those mechanical, biomedical, and technological improvements that enhance, restore, or sustain health.

Study tasks shall include, but not be limited to, the following:

a. Identify specific requirements for Soldier cognitive, physical, and mental enhancement.

b. Review research efforts on Soldier enhancement in the Army, and on

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human enhancement in other military services, the National Institute of Health, industry, and academia.

c. Review efforts of other countries to investigate and apply this technology to their military force.

d. Analyze and recommend best practices applicable to Soldier enhancement.

The study should provide an independent report of its deliberations, findings, and recommendations, as well as cooperate with and provide its results to the parent ASB study on "Disruptive Innovative Concepts for the Future Army."

The Commanding General, U.S. Army Training and Doctrine Command is the sponsor of this effort. The G-3/5/7 will assist the study team in accessing classified information up to Top Secret and including Sensitive Compartmented Information and Special Access Programs. The Board will provide a briefing and report with findings and recommendations by September 30, 2016 to me and the Chief of Staff, Army.

The study will operate in accordance with the Federal Advisory Committee Act and DoD Directive 5105.4, "DoD Federal Advisory Committee Management Program." I do not anticipate that this study will need to go into any "particular matters" within the meaning of Title 18 United States Code Section 208, nor will it cause any Board member to be placed in the position of acting as a procurement official.

Sincerely,

Eric K. Fanning
Acting

APPENDIX B – STUDY TEAM MEMBERS

MG (R) Lester Martinez-Lopez, M.D. (USA Ret.)
Chair

Jill Harp, Ph.D.
Vice-Chair

Endy Daehner, Ph.D.

BG David Fastabend (USA Ret.)

Deanne J. Idar, Ph.D.

Margaret Kulungowski

Maria Mouratidis, Ph.D.

Mary Crannell
Senior Advisor

COL Peter Im
MCoE Advisor

Nancy Chesser, Ph.D.
ASB Integration Team Liaison

Study Managers:
Justine Federici
MAJ Michael Dretsch
MAJ Jerry Mize

Mark Swiatek
Tech Writer/Editor

APPENDIX C – ASB APPROVED BRIEFING WITH FINDINGS AND RECOMMENDATIONS

Army Science Board

Army Efforts to Enhance Soldier Performance

28 July 2016

Army Science Board 1

Outline

- Introduction
- Call to Action
- Definitions of Terms
- Observations & Findings
- Findings & Recommendations

Army Science Board 2

Introduction: Study Team

Chair – MG (R) Lester Martinez-Lopez

Vice-Chair – Jill Harp

Panel Members
Endy Daehner
David Fastabend
Deanne J. Idar
Meg Kulungowski
Maria Mouratidis

Senior Advisor – Mary Crannell
MCoE Advisor – COL Peter Im
Study Managers – Maj Michael Dretsch, Justine Federici, Maj Jerry Mize
Integration Team Liaison – Nancy Chesser
Tech Writer/Editor – Mark Swiatek

Army Science Board 3

Introduction: Terms of Reference (TOR)

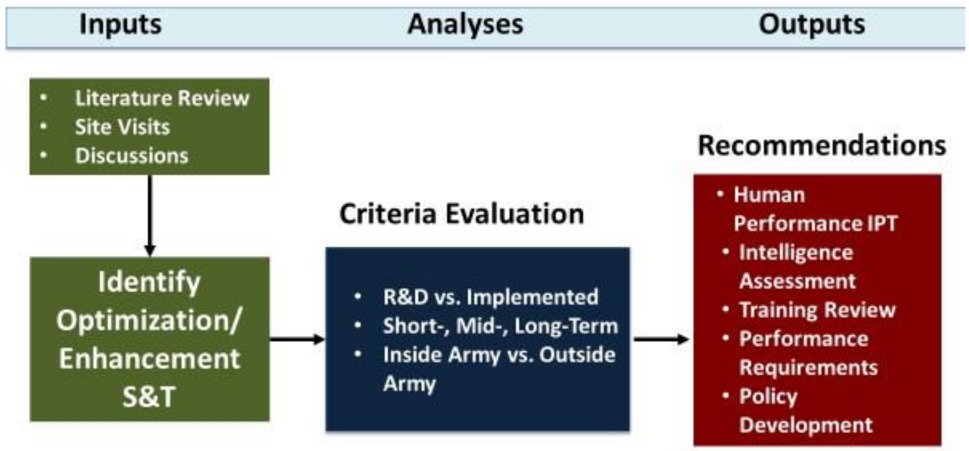
Tactical complexities demand improved cognitive, physical, and mental capabilities, as well as increased physical, technical, and cultural aptitudes from each Soldier, in every mission.

To examine potential future requirements in this area, CG TRADOC asked the study team to conduct the following:

- Assess the Army's current efforts associated with Soldier enhancement, and compare those to efforts occurring outside the Army.
- Analyze trends in human enhancement for relevant application to future force capabilities and consider risks of application within the military.
- Consider whether and how cultural values of foreign nations may facilitate the development and application of enhancements that the U.S. Government would see as more extreme or unethical.

Army Science Board 4

Introduction: Study Approach



Introduction: Data Collection – Over 40 Visits & Interviews

Army

- Army Research Lab (ARL)
- Assistant Secretary of the Army (Acquisition, Logistics and Technology)
- Aviation and Missile RDEC (AMRDEC)
- CSA Strategic Studies Group
- Environmental Medicine (USARIEM)
- Human Research Protection Office (HRPO), Ft Detrick
- Medical Research and Materiel Command
- MCoE - Human Dimension, Ft Benning
- Natick Soldier RDEC (NSRDEC)
- Redstone Arsenal
- Special Warfare Education Group (SWEG), JFK Special Warfare Center and School, Ft Bragg
- Software Engineering Directorate
- UARCs: Institute for Nano Technology (ISN), Institute for Collaborative Biotechnologies (ICB), Institute for Creative Technology (ICT)
- U.S. Army Research Institute of U.S. Military Academy, West Point (Performance Enhancement Program & Eng. Psy. Dept.)
- Soldiers: 82nd ABN Division

Other DoD

- Air Force Research Lab (AFRL)
- DARPA
- DIA, National Center for Medical Intelligence
- Office of Naval Research (ONR)
- Office of the Surgeon General

Other Government

- Intelligence Advanced Research Projects Activity (IARPA)

Academia/FFRDC

- Auburn University, School of Kinesiology
- Draper Laboratories
- Institute for Soldier Nanotechnology, MIT
- Lincoln Laboratory, MIT
- Massachusetts Institute of Technology (MIT)
- Perelman School of Medicine, Laboratory for Cognition and Neural Stimulation
- Tufts Center for Applied Brain & Cognitive Science
- Univ of California San Francisco, Neurology Dept.
- Univ. of Miami, UMindfulness Initiative
- Univ. of Penn, Center for Neuroscience & Society
- Univ. of Pittsburgh
- Ethics + Emerging Sciences Group, California Polytechnic State University

Industry

- GE Global Research
- Mind + Matter LLC
- Microsoft

Other

- U.S. Anti-Doping Agency
- U.S. Olympic Committee
- Extensive Literature Search

A Call to Action: *Strategic Choices at the Inflection Point*

- ***Ubiquitous, expanding, accelerating*: Human Optimization/Enhancement is here. We cannot 'Opt Out'**
- **These technologies are non-linear differentiators. We can …**
  - **… risk strategic surprise, or**
  - **… seize the opportunity and make it a game changer**
- **Human Enhancement will come at us. We can …**
  - **… understand and appreciate it**
  - **… mitigate its impact**
  - **… be prepared to employ it as directed**
- **Human Enhancement already happening in our Army. We can …**
  - **… ignore and accept impacts, or**
  - **… shape an inevitable phenomenon**
- **Future Army: smaller, in an Operating Environment of even greater performance stress. We can …**
  - **… hope for the best, or**
  - **… leverage our most important asset: the Soldier**

Army Science Board 7

Definitions & Scope

WHAT? Optimize/enhance performance in the three domains:

- ***Physical*** - relating to the body (including the brain) other than the mind
- ***Cognitive*** - intelligence (*fluid and crystallized*), executive functions (e.g. attention, mental flexibility, executive cognitive control, response inhibition, decision making, problem solving, motivation, impulsivity, etc.), memory, language, motor functioning, perception, visuospatial skills, insight, and judgment.
- ***Psychological*** - emotions (emotional regulation), attachment, and personality hardiness, grit, motivational factors, resilience, adaptability, maturity, empathy, impulsivity, risk taking, frustration tolerance, leadership, flexibility, and social interactions

HOW? Means to optimize & enhance

- ***Pharmacological*** (molecular)
- ***Biological*** (cellular)
- ***Technological*** (software & hardware)
- ***Education & training***

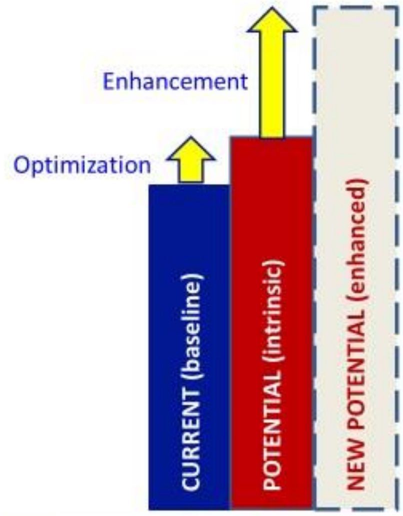
Army Science Board 8

Definitions

HOW MUCH? Capacity & level

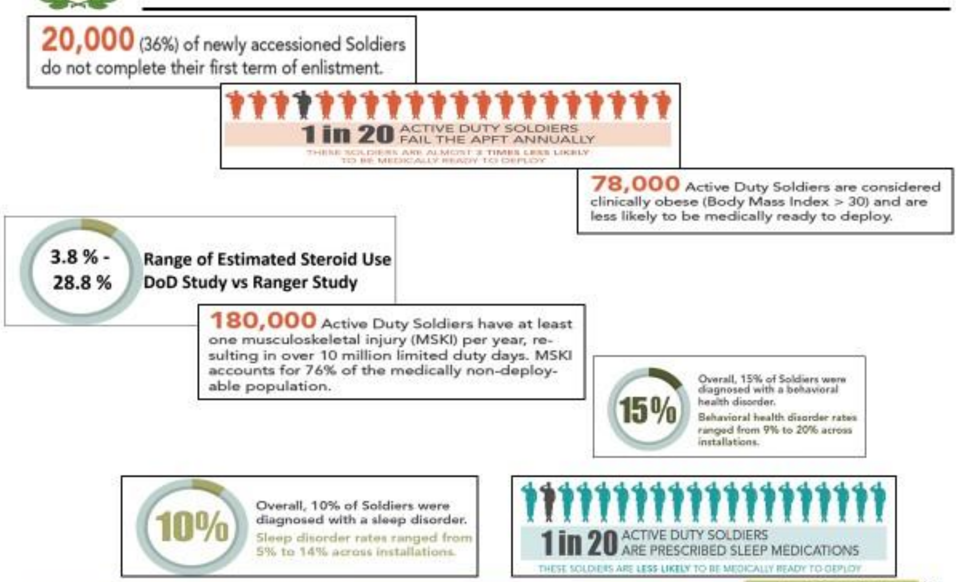
- ***Optimization:***
  The process to maximize the intrinsic performance capacity and level

- ***Enhancement:***
  The process to expand the maximum intrinsic performance capacity and level



Army Science Board 9

Observations: A Case for Optimization



Army Science Board 10

Observations: Generational Landscape

- Army Soldiers bridge 4 "generations"
- New Boots: Millennials & Digital Natives
  - Different brain neural circuitry & enhanced multi-tasking skills (fMRI)
  - Enhanced complex reasoning and decision-making
  - Reduced deep learning
  - Diminished "people" skills
    - Diminished emotional aptitude (e.g. empathy)
    - Challenges with social interactions & teaming

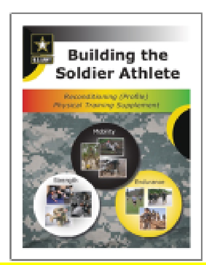
Finding: Soldier generations have distinct cognitive-psychological strengths and weaknesses

Army Science Board 11

Observations: Physical Domain Optimization

- Optimization
  - Tension between institutional physical standards and individual optimization
  - Army has developed gender neutral standards for combat arms overall
  - Technologies are available today to assess and guide individual optimization (MOS task specific)
  - Opportunities in individual nutrition (education, behavior modification, dietary access)

"I want to improve. I reach a peak and then I'm like alright, what do I have to do to get better...If I see someone that is in a better state than me, I want to know what they are doing." **82nd Airborne Soldier**



Finding: Army common standards approach to physical training restricts ability to support individual physical optimization

Army Science Board 12

Observations: Physical Domain Enhancement

- Promising technologies to enhance physical performance (Speed, Endurance and/or Strength) are:
  - ST: Exoskeleton
  - ST: Pharmacological agents
  - MT: Skeletal muscle mitochondrial biogenesis
  - MT: Tissue regeneration technology
  - MT/LT: Gene editing (e.g. CRISPR) technology to engineer the human being

"If we can carry faster and farther, guess what we can do at the end state? We can fight better."
82nd Airborne Soldier

ST = short-term (0-5 yrs.)
MT= mid-term (5-10 yrs.)
LT = long-term (10-20 yrs.)

CRISPR = Clustered Regularly Interspaced Short Palindromic Repeat

Army Science Board 13

Observations: Cognitive Domain Optimization

- Promising optimization efforts include
  - ST: Retooled educational processes and educators
  - ST: Adaptive learning (individual and team)
  - ST: Mindfulness training – improved alertness, attention, & memory
  - ST: Cognitive exercises
  - ST: Assimilation learning (augmented & virtual reality, avatars & simulators)
  - MT: Decision support (AI)
  - MT: Research on optimizing both roles of man-machine teaming
  - LT: Convergence of assimilation learning and AI

Finding: Man-machine teaming will be a key issue in future developments for both Soldier optimization and autonomy

Army Science Board 14

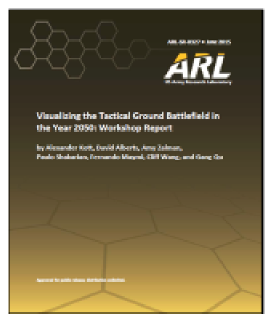
Observations: Cognitive Domain Enhancement

- Cognitive enhancement research landscape; most technologies are <u>nascent</u>
  - Brain mapping effort (conclude in ~ 10 years) to identify & enhance brain functions
  - Neuroimaging, e.g. optogenetics, very immature, but critical for cognitive field advancement
  - Roles of epigenetics & microbiomes in cognitive function
- Promising cognition enhancement technologies to enhance crystallized intelligence, executive functions and mental processes
  - ST: Pharmacological agents, e.g. Ritalin
  - MT: Electrical, magnetic & ultrasound brain stimulation
  - MT: Intra-cortical microstimulation
  - MT: Intracranial stimulation
  - MT/LT: Gene editing (DNA & RNA)
  - LT: Computer-brain interface
- Fluid intelligence enhancement may have biological limits

Army Science Board 15

Observations: Psychological Domain Optimization

- Promising Optimization Efforts include:
  - ST: Mindfulness Training
  - ST: Optimized sleep
    - Sleep assessment tool (enhanced 2BAlert)
    - FAST (Navy effort)
  - ST: Nutrition to optimize emotional regulation, e.g. Omega-3
  - MT: Stress recognition tools – facial & voice variations
  - MT: Psychology of man-machine teaming
    - "Ensuring appropriate levels of trust can be a particular challenge to the successful integration of robotic assets in human teams." (Freedy et al., 2007)



Army Science Board 16

Observations: Psychological Domain Enhancement

- Promising psychological enhancement technologies to enhance emotional regulation, hardiness, grit & motivation
  - ST/MT: Pharmacological agents, e.g. propranolol, to improve emotional regulation
  - MT/LT: Electrical, magnetic & ultrasound brain stimulation to improve overall psychological targets (plus sleep deprivation)
  - MT/LT: Hypothalamic prosthetics in the brain
  - MT/LT: Gene editing (e.g. CRISPR)

Army Science Board 17

Technology Opportunities: Physical, Cognitive, and Psychological Domains

Development & Fielding
- Exoskeleton Experimentation and Prototyping
- Sleep Assessment Tools
- Mindfulness Training
- Optimal Performance sensing, assessment and training
- Assimilation Learning
- Decision Support Artificial Intelligence
- Pharmacological Agents

Research
- Convergence of assimilation learning and AI
- Psychology of Man-Machine Interaction
- Distress recognition of facial expression and voice variations
- Pharmacological Agents
- Skeletal muscle mitochondrial biogenesis

Exploration
- Intra-cortical microstimulation
- Intracranial stimulation
- Electromagnetic, ultrasound and brain stimulation
- Hypothalamic prosthetics
- Computer-Brain interface
- Pharmacological Agents
- Gene Editing

Finding: Soldier Optimization and Enhancement Technologies are at disparate levels of readiness for development & fielding, research, and exploration

Army Science Board 18

Observations: Threat

"Cutting edge research in medicine aimed at improving humans with super abilities in extreme conditions, super attention, super endurance, and super intelligence."

Open Source Stated Goal: Russian Advanced Research Foundation

"Second Chinese team reports gene editing in human embryos…" (08 Apr 2016)

Russian use of anabolic steroids called (NY Times) "One of the most elaborate and successful doping ploys in sports history"

Chinese National Planning Document: *"Identify human reproductive engineering as critical to support the strategic policy of producing quality children"*

Russia and China heavily invested in gene editing research

Finding: Our adversaries are actively pursuing R&D and deployment of Human Enhancement technologies

Army Science Board 19

Observations: *Ethical and Cultural Asymmetry*

US

- Laws and conventions
- Free will - informed consent process needed
- Long term effects, no harm to the Soldier
  - Enhance benefits and mitigate potential effects
  - Transient vs. permanent effects
- Implications for return to civilian life

OTHERS

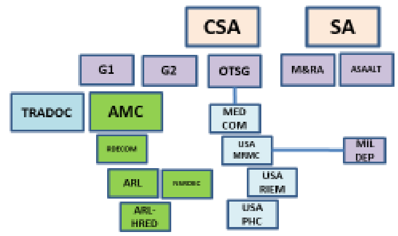
- May not share our ethical interpretations based on socio-cultural differences

Finding: Our adversaries may have very asymmetric perspectives on the ethical interpretations associated with the development and employment of this technology

Army Science Board 20

Observations: Ambiguous Responsibility

- Optimal lines of responsibility and authority not obvious
- Available talent weighted within MEDCOM but medical community perceive ethical dilemmas
- Need to allocate lead / support relationships for:
  - Policy Coordination
  - R&D Program Development
  - S&T Integration
  - Tech Watch



USARIEM: Research Institute of Environmental Medicine
USAMRMC: Medical Research and Material Command
ARL: Army Research Lab
USAPHC: Public Health Command (CHPPM)
ARL-HRED: ARL Human Research & Engineering Directorate
NSRDEC: Natick Soldier RD & E Center

Finding: Allocation of responsibility and authority lacks clarity and institutional buy-in

Army Science Board 21

1. Recommendation: Human Performance IPT

Finding: Soldier Optimization and Enhancement Technologies at disparate levels of readiness for development & fielding, research, and exploration

Finding: Allocation of responsibility and authority lacks clarity and institutional buy-in

Recommendation: SA and CSA charter an IPT to conduct a one year Human Performance Study to explore the potential of these technologies

IPT Composition:

G3/5/7	M&RA
G2	ASAALT
SJA	OGC
TRADOC	
FORSCOM	
OTSG / MEDCOM	
AMC / RDECOM	

Study Tasks:

Recommend lead / support responsibility for …
- … Policy Coordination
- … R&D Program Development
- … S&T Management / Integration
- … Tech Watch

Assess ASB human performance technology opportunities for feasibility, time frame and level of effort with respect to …
- … development & fielding
- … research
- … exploration

Army Science Board 22

2. Recommendation: Intelligence Assessment

Finding: Our adversaries are actively pursuing Human Enhancement technologies

Recommendation: SA and CSA task Army G2 (assisted by MEDCOM & AMC) to develop a recurring, all-source, integrated intelligence assessment of global threats with respect to talent deployment, Human Performance Optimization and Enhancement technology development and deployment

Army Science Board 23

3. Recommendation: Training Review

Finding: Soldier generations have distinct cognitive-psychological strengths and weaknesses

Finding: Man-machine teaming will be a key issue in future developments for both Soldier optimization and autonomy

Recommendation: SA and CSA task TRADOC to ...

... maintain efforts that adapt individual and collective training and education programs to leverage emerging generational cognitive-psychological advantages while mitigating their vulnerabilities

... extend TRADOC Human Dimension effort to address man-machine teaming

Army Science Board 24

4. Recommendation: Performance Requirements

Finding: Army common standards approach to physical training restricts ability to support individual physical optimization

Recommendation: SA and CSA task TRADOC (with assistance of G1 and MEDCOM) to extend common and MOS task-specific performance requirements beyond combat arms MOS's in order to inform individual physical optimization effort

Army Science Board 25

5. Recommendation: Policy Development

Finding: Our adversaries may have very asymmetric perspectives on the ethical interpretations associated with the development and employment of this technology

Recommendation: SA and CSA charter Office of General Counsel, in coordination with internal and external stakeholders, to develop acceptable ethical and legal policies for development and exploitation for these technologies

Army Science Board 26

Closing

Breaking Defense: DIU(X) Funds Brain-Hacking Headset

"The biosciences, like all technologies in the past, will be used for good and for ill. Our job is to make sure that our society is protected and that our military is at the frontier of that field."

Secretary of Defense Ashton Carter
26 July 2016

DIU(X) Funds Brain-Hacking Headset; Boston Branch Opens

UPDATED: Carter Touts Import Of Biotech

CAMBRIDGE, MASS.: Special operations troops will test a high-tech headset that "uses noninvasive electrical stimulation" to help the brain learn better marksmanship and hand-to-hand combat skills, Defense Secretary Ashton Carter said here today. This cutting edge example of "enhanced human operations" — a highly controversial field — is just the first commercial project funded by Carter's recently reorganized Defense Innovation Unit (Experimental), DIU(X).

Army Science Board 27