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MASTER OF OPERATIONAL STUDIES

NEURO-NAVY: THE IMPACT OF FUTURE NEUROFEEDBACK ADVANCES ON NAVAL FORCES

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF OPERATIONAL STUDIES

LCDR ADAM J. KRUPPA, USN

AY 12-13

Senior Mentor: Bradley Meyer, PhD

Approved: Bradley Meyer

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Executive Summary

Title: Neuro-navy: The impact of future neuro-feedback advances on naval forces.

Author: LCDR Adam J. Kruppa, United States Navy

Thesis: Research advancements in neuro-feedback will improve future naval capabilities in sensory processing, motor skill adaptation, cognitive executive functions, and brain-machine interface control.

Discussion: The human mind’s capacity is the essence of man’s wartime capability and thus the impact of advances in neuroscience is worthy of a future war consideration. This study explores how research advancements in neuro-feedback will improve future naval capabilities. The application of brain scans has determined that our brain is organized in functional regions that activate during specific types of thought, action, or thoughts required prior to the action. This finding has launched the professional field of neuroscience to new research endeavors, focusing on specific neural regional functions and capacities.

Neuro-feedback refers to the ability and technology to monitor and process neural activity during thought and action. It is a non-invasive procedure that measures electrical signal transmission and activity across the top layer of the skull. This procedure has rapidly increased the understanding and research in the field of neuroscience and has led to further advances in feedback measurement. In the future, this technology will move from the current bulky, immobile limitations to a lightweight, non-distractive, portable device. Either worn as a small appendage or installed in common headgear, this Neuro-Feedback Device (NFD) will provide naval warriors with a highly advantageous neurological monitor and training tool to enhance cognitive ability and improve sensory processing.

Conclusion:

The future application of NFD requires further development in the appropriate means to employ the most effective plasticity. Until the stability-plasticity dilemma is further understood and the ‘critical periods’ of neural integration are opened to adults, specific areas of the brain may remain shut off. These eventual developments will lead to NFD’s ability to target weaknesses and refine naval training to act upon the correct functional neural actions. As NFD activity is mapped and linked at team level, naval commands will be provided readiness and training programs to address degradations in pertinent categories required for complex operations.

The challenge for naval leaders is to embrace the differences between the varying performances of the brain regions and determine a developmental plan to enrich the areas that NFDs assess as deficient. Evaluating at-sea sensory and motor skill performance quickly and accurately will only be capable by a rapid NF assessment. The NFD will not only establish neural baselines for all sailors onboard, but will lay the foundation for a robust neural developmental plan focused on challenging the brain’s plasticity to improve cognitive ability, sensory processing, and an enhanced brain-machine interface.
DISCLAIMER

THE OPINIONS AND CONCLUSIONS EXPRESSED HEREIN ARE THOSE OF THE INDIVIDUAL STUDENT AUTHOR AND DO NOT NECESSARILY REPRESENT THE VIEWS OF EITHER THE MARINE CORPS SCHOOL OF ADVANCED WARFIGHTING OR ANY OTHER GOVERNMENTAL AGENCY. REFERENCES TO THIS STUDY SHOULD INCLUDE THE FOREGOING STATEMENT.

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INTRODUCTION

When looking at proposed future war situations, many warfighters may focus on advanced weaponry or maneuver platforms. Future war theorists discuss geostrategic considerations or fiscal creativity. Yet the common denominator amongst most military actors is still the human. The human mind’s capacity is the essence of man’s wartime capability and thus, the impact of neuroscience advances is worthy of consideration in future war. This study explores how research advancements in neurofeedback will improve future naval capabilities in sensory system processing, motor skill adaptation, cognitive executive functions, and brain-machine interface.

Sailors make decisions and perform actions, sometimes life-dependent, on a frequent basis. The ability to enhance naval warriors cognitive and subconscious abilities through neurofeedback requires an understanding of the separate functions of the various regions of the brain. Prior to the current understanding, the brain was believed to act as a reductive organ or, to be comprised of just two sides working together. Yet, after decades of research, the evolution and application of brain scans has determined that the brain is organized in functional regions that activate a choreography of specific types of thought and action. This led to associated neuroscience research that focuses on specific neural regional functions and capacities.

In addition to understanding the regional functions of the brain, neuroscientists strive to capture the neural system’s connections and timing. Neurofeedback refers to the technology and process of monitoring neural activity during thought and action. It is a non-invasive procedure that measures brain signal activity in specific regions and across the top layer of the skull. The outer layer of the brain, the cerebral cortex, comprises the primary function of memory, attention, thought, and consciousness. Scientists have categorized the cerebral cortex into four
main lobe areas, which process sensory information (visual, auditory, touch) from other regions of the brain. The cortex includes regions known as motor areas that control voluntary muscle movement and association areas (parietal, temporal and occipital lobes) that produce perceptions.¹ Neuroscientists explore the interactive activity of the various regions to determine association with thoughts and action. Ranging from the importance of the limbic region for emotional activity to facilitating the silencing of neurons in the Pre Frontal Cortex to cause an effect in the basal ganglia region,² the field of Neuroscience (only in it’s infancy) is in the process of mapping all the regions for associated brain activity. As announced by President Obama in April of 2013, new initiatives in this immense unknown field will “open new doors to understanding ...brain function”³ and groundbreaking research will provide a substantial payoff to future measurement and feedback applications.

Measuring the activity in brain regions has evolved from basic chemical and radiological brain measurements (EEG and PET) to magnetic readings of blood flow that depict micro-activity in specific neural regions (functional Magnetic Resonance Imaging or fMRI). A fMRI allows subjects limited freedom for small movements and tasks during the thorough scan to show the linkage of brain and body activity. This procedure has rapidly increased neuroscience understanding and research, leading to dramatic advances in feedback measurement.⁴ Although the fMRI has the ability to measure activity in various regions deep inside the brain (unlike the topical area of EEGs), the real-time measurement and resolution is limited. Combining multiple neurological scanners to complement each other (such as fMRI and EEG) will have a large payoff in the ability to quickly conduct thorough, high-resolution, real-time neural scans.

In the future, this technology will move from the current bulky, immobile limitations to a lightweight, non-distractive, portable device similar to a small EEG such as “Emotive” (Figure
1) or “Neurosky” (Figure 2.) Either worn as a small appendage or installed in common headgear, the future Neuro-Feedback Device (NFD) will provide naval warriors with a highly advantageous neurological monitor and development tool to enhance overall performance at sea. Current technologies are advancing near-real time feedback devices, as data transfer and sharing strive to further reduce communication loops through real time common gateways. The future NFD will incorporate real-time monitoring with a graphical user interface, such as a stoplight chart, to provide the sailor with the neural status of various regions of the brain. Although too much feedback, too quickly, may inhibit decision making during complex situations, a properly developed future NFD will provide the balance required to “enhance the [sailors] mental ability to analyze their decision making process” through harnessing NF and homeostatic plasticity.

Neural plasticity involves neural networks physically changing size. Just like bodybuilding, humans activities enlarge and stretch brain regions due to cognitive strengthening and their own experience, while a lack of activity results in shrinking. Many are amazed to find that cab drivers in London were evaluated to have an enlarged hippocampus (the region responsible for 2D spatial ability) and the most experienced cabbies have the densest spatial regions. Recent findings have shown that neural plasticity can be changed by a display of current, real-time neural status combined with focused activity. By this empirical use of neurofeedback, humans ‘learn’ when they are activating specific neural areas. This optimal neural state is then easier to replicate in future scenarios. An individual watching his brain activity on a monitor is able to quickly adapt and start controlling his focus and activity amongst the responsible neural regions. Sailors using NFD linked with associated neural mapping will have access to displays of their real-time functional neural activity levels for focused, on-the-spot adjustment or growth in sensory system processing, motor skill proficiency, and cognitive tasks.
SENSORY SYSTEM PROCESSING

From a forward lookout to a radar operator to an engine room watchstander to a sonarman, sensory skills are consistently stressed and stretched on naval units at sea. Sensory reception tasks commonly refer to the visual, auditory, and somatosensory cortex regions of the brain. These cortices receive inputs from all over the body while the parietal cortex interprets these sensory neuron inputs. With sailors predominantly seeking an initial input from the visual cortex, future advances in sensory processing will enhance the future naval force. The capacity to increase visual plasticity is higher than originally expected, as human eyes process visual data at a much smaller rate than designed. As Henshaw details, normal eyes transmit data at 9 megabytes per second, yet are capable of speeds several hundred times faster.\textsuperscript{12}

Recent intelligence analysis research has shown the potential for rapid visual processing of thousands of satellite imagery and mega-live video feeds, such as ARGUS 2.\textsuperscript{13} The future ability to measure sailors' visual sensory activity and provide real-time tools for investigation into previously unseen items provides a highly enhanced naval force optimized to use technology to gain expedient situational awareness quicker than an adversary. NFDs will improve the reliance on visual sensory through real-time monitoring and alerting of visual processing competence.\textsuperscript{14} NFDs will provide the status of the sailor's brain regions responsible for visual sensory collection, interpretation, and also non-visual inputs responsible for interpreting location.\textsuperscript{15} With NFD, maritime boarding party officers will have real-time feedback on visual cues obtained on suspect vessels that link to the limbic activity to provide enhanced cognition and intuitive decision-making. A naval aviator will receive NFD alerts of potential surface or air contacts initially missed by radar or first glance and coupled with eye-gaze tracking software,\textsuperscript{16} guiding her to reassess the situation. While assessing self-biological data, she will conduct a
simultaneous, second contact search assisted with a neurally accessed onboard, threat database.

Beyond visual stimuli, naval warriors will increase auditory ability in sensory-enhanced intelligence collection and analysis, providing the framework for an ability to receive more inputs, quicker. Research is identifying the missing links of the mammalian hearing process; advancing the ability to measure auditory brain processing with portable devices.¹⁷ Medical advances to improve hearing deficits in humans rely on a replacement signal transmitter that stimulates cochlear nerve cells, resulting in repair of a broken link between the brain and outside noise. This system relies on the neural plasticity of the brain to build upon amplified signals and learn to hear those once-missing signals.¹⁸ Aside from pure volume amplification, human signal processing, coupled with NFD, will result in increased sailor comprehension of low signal transmissions and detailed analysis of passive narrowband sonar audio feeds (previously outside the frequency range of normal human hearing.) Through NFD system’s advanced understanding of auditory brain function, future naval watchstanders will have increased communication ability with on and off-ship watch teams. Just as select individuals have mastered the ability to read text at rapid pace, the repetitive use of NFD to enhance auditory processing will allow for simultaneous audio processing at much higher speeds. In training modules, apprentices will be exposed to gradual increasing amounts of audio feeds. From the neural feed of the NFD, associated activity from responsible brain regions will provide an updated display of the sailor’s auditory homeostasis. Similar to monitoring the RPM or MPG in a car, the trainee will self-assess the neural activity in his auditory brain regions, and will contribute to a new naval force, full of ‘aware’ warriors capable to tweak their auditory processing to a higher level.

Understanding and harnessing the remaining senses such as touch, smell, and proprioception are important as they provide opportunities for advancing full NFD sensory
processing capacity and lead to further research in the various brain regions that activate during routine tasks at sea. Holistic sensory control will improve more specific areas, as observed in blind patient use of sonar which increased visual cortex brain activity equal to that of patients with normal vision. NFDs will combine multi-modal sensory stimulation to previously unknown connections in overall sensory and cognitive performance. As Poldrack determined, specific skills require learned patterns and through practice, utilization of more skilled brain regions will result in decreased cognitive workload. Energy savings in cognitive brain regions (such as the PFC) activate previously uninvolved neural regions with learning and adaptation. This wide ranging neural exposure will enable new motor skill improvements, such as advanced language proficiency, in which multiple regions will be primed to learn new sounds.

NFD will identify individual sensory skills requiring improvement or those out of sync. Based on the task(s) required, the NFD will queue the wearer to sensory-based brain fitness designed to improve the sailors ability, such as scenario-based video games designed to improve spatial skills. The NFL wide receiver marvel, Larry Fitzgerald, is touted for his exceptional catching ability and impossible feats, yet when asked about his childhood he has admitted to quirky one-eyed catching drills focused on improving his senses combined with motor skill development. Similarly, during neural battle drills, sailors will be able to review hundreds of threat radar recordings training their intuitive mind to ‘see’ the threats that were once invisible and prime their pump for upcoming sensory collection duties.

The aggregate sensory data from NFD will provide senior commanders an additional tool to review ship readiness and decide optimal mission platforms. The DESRON Commodore will review the sensory neural activity of his ships to aid in assignment of a picket ship – as one combatant may be outperforming other units in pertinent areas such as EW or SIGINT. The
NFD will enhance readiness as commanders and staff will review each ship’s immediate neural fatigue status or design long-term training plans to address specific neural weaknesses.

**MOTOR SKILL ADAPTATION**

Despite any anaerobic gift a sailor may have, the brain is the primary mover for motor skills. As a system for operating in everyday life, motor skills are those that are voluntary and non-declarative, not requiring mental facts or event memory recall to be performed. The impact of motor skill efficiency has been evident in military studies for numerous decades and endures as operational success hinges on the ability of sailors to conduct specific tasks associated with the maritime domain. The brain regionalization model identifies that neural specialization is fundamental to the performance of skills. In a research assessment of elite soccer players, Beilock found that professional players did not differ from amateur players in basic human motor skills (tracking and response), yet when compared in a soccer-specific environment their performance of specialized tasks (reaction, tactical decisions, situational awareness) was greatly differential. To increase motor skill ability, compiling a database of warrior performance skillsets is imperative. NFDs will provide naval forces access to the neural patterns required for sailor-skilled tasks and allow assessment of effective performance across the conflict spectrum.

Neuro-Developmental Therapy (NDT) has shown that natural and repetitive movements will change and adapt neurons. Jugglers that stop their skill are observed to have specific regions shrink in density which were originally enlarged during juggling proficiency. Young children exposed to playing musical instruments display increased motor skills (beyond just musical tasks) and more brain white matter, than children exposed at an older age with less repetition. While professional baseball batters can only swing at 90+ mph pitches intuitively and rely on their stellar motor skills, those athletes who regularly reflect on their own body
motion and motor skills tend to choke under pressure. NFD will ensure proper balance of motor skill activity with different cerebral cortex regions responsible for controlling various bodily functions and therefore facilitate superior skill adaptation and improvement.

Although neuro-feedback will require scientific advances to overcome the unknown holistic aspects of the brain involved in shared aspects of function, future NFD will leverage advanced findings in task-specific mapping (Such as the B.R.A.I.N. initiative) so that critical maritime activities may be monitored in real-time. Just as brain waves of multiple individuals are literally synchronizing to coordinate and conduct motor skills, NFD will provide naval warriors, their teammates, and leaders with maritime-specific brain activity mapping for use in individual and team motor skill development plans. The development of multi-controller autonomous vehicles will rely on accurate neuro-feedback, while advances in weapon login and firing may rely on unique neural activity. Recent success in blended reality is providing aviators the ability to conduct motor skill training in a hybrid environment, presenting a model for future NFD motor skill adaptation that will blend neural activity with actual training and improve autonomous vehicle control. These advances will substantially improve naval capability, yet without cognitive improvement a neural device is not a wise investment.

COGNITIVE EXECUTIVE FUNCTIONS

The prefrontal cortex (PFC) is a vital area of the brain associated with a sailor’s level of executive function through the cognitive processing and control of specific areas of short-term memory. This region has a significant impact on a sailor’s decision making ability while also controlling the emotional urges that are continually present in the limbic region. The PFC transposes the important parts of short-term memory into the working memory, for the processing, disposal, and retrieval of information at the right location and time for executive
action. 38 This process is not merely a method of storing and recalling memory, but a complex interchange of simultaneous neural activity between memory, patterns, and perception occurring in multiple regions of the brain. 39

Under low-stress decision-making environments the working-memory and the PFC provide the sailor with ability to recognize patterns and rationalize problems. 40 The brain sorts through numerous inputs, categorizes them, and creates patterns. 41 It is too difficult for the brain to remember and correlate each input with previously held memory. Professional speed chess players excel due to their ability to quickly learn meaningful patterns specific to the game 42 whereas if those players attempted to play simply by rules, they would be stuck in paralysis. 43 The PFC’s control of limited working memory items 44 quickly and efficiently determines a sailor’s decision-making mastery. 45 NFD will harness the PFC signals and pattern recognition and will not only monitor these signals, but will predict upcoming cogent activity and further modify the rhythmic control used for interpretation and transmission. 46 Linked with NFD, neural strengthening equipment such as strobed-eye wear will boost short-term visual memory 47 while the use of optogenetics will provide device-mediated intervention in very specific regions of the brain resulting in the ability to inhibit anxiety. 48

As important as the ability to calculate, plan, and rationalize is, so are the emotional (limbic) regions of the brain. Located outside the cortex, (once thought of as the primitive section of the brain) the amygdala and associated emotional regions are identified as pertinent aspects of the overall cognitive ability. The emotional attributes of the brain provide the foundation for many intuitive decisions. 49 From athletes to businessmen to directors, multitudes of professionals admit that emotionally-based intuition plays a significant role in their decision-making process and overall cooperation abilities. 50 Women with damaged amygdala (resulting
in no fear of external threats) displayed internal fear (panic) brain activity, leading researchers to deduce that the amygdala also functions to inhibit internal panic and enhance executive function.\textsuperscript{51} Additionally, fear and activity in the amygdala recently were shown to have a direct impact on one's spatial perspective;\textsuperscript{52} further strengthening the need to seek an understanding (through NFD monitoring) of its neural activity during decision making. Just as the baseball batter swings intuitively, the emotionally connected brain decides quicker than a purely rational PFC. This innate ability ensures that complex situations are not a no-hope situation, since at times warfighters unconsciously resort to their emotional side for the best decisions, such as LtCdr Riley's correct intuitive decision to launch self-defense missiles at radar contacts, that he 'felt' were incoming missiles. Gary Klein later proved that LtCdr's decision cycle was outside the realm of rational decision making.\textsuperscript{53}

The NFD ability to measure and monitor the amygdala's activity will improve the warfighter's cognitive ability during complex situations. Brain scans reveal that even during rational thought processes, the limbic system is continually active, promoting the notion that the PFC is a controlling aspect of emotions.\textsuperscript{54} During complex problems the PFC becomes overwhelmed and loses control of the emotional side causing impulsivity and loss of inhibitions.\textsuperscript{55} Conversely, the overabundance of emotional state of bliss caused by excess dopamine in the brain can have a detrimental effect on the executive function of warfighters within dopamine-laden environments or whom exhibit attention deficit disorders.\textsuperscript{56} Yet, excessive rationality and overpowering conscious thought from the PFC can result in too narrow of a focus and overthinking the problem, possibly choking when under pressure.\textsuperscript{57} In a study of professional athletes, those athletes were both aware of the state of their limbic region and able to maintain a superiority of intuitive decision-making, created balanced neural activity and
prevented paralysis through analysis.\textsuperscript{58} Contrary to earlier theories, the limbic system exhibits plasticity, selectivity, and adaptation and can coexist with other neural activity.\textsuperscript{59} During sleep, specific regions are suppressed to maintain areas more critical for declarative memory.\textsuperscript{60} With NFD programmed to provide feedback at the optimal time and region(s), a sailor will experience advantageous plasticity.\textsuperscript{61}

The incorporation of NFD will provide naval warfighters real-time status of a cognitive rationality-emotion balance. Pure rationality is an executive impairment\textsuperscript{62} while the complete lack of a working PFC creates a danger to an effective naval command.\textsuperscript{63} Striving to strike a balance and enhance both aspects will create a force multiplier at-sea, able to make continued superior decisions during stressful situations. Working with two or more brain regions simultaneously increases the cognitive ability of an individual\textsuperscript{64} and furthermore, the advanced ability to simultaneously use various regions conserves PFC energy consumption, thus allowing potential for additional rational choices or emergent tasks.\textsuperscript{65} At sea, naval leaders (via NFD) will assess the cognitive capability and workload of teams and/or commands to determine requisite training and rest. Senior Watch Officers will have a new tool to input watchbills for optimal neural states. Additionally, naval leaders will assess team dynamics amongst leader presence to determine optimal team makeup and chemistry. Through NFD data, 360-degree leadership assessments will include neural performance as indicators of leadership ability.

The NFD will increase sailor convictions of what is possible. For decades the Israeli Air Force incorporated a computer game designed to boost trainee’s memory and attention skills. Unexpectedly, it resulted in overall improved fighter performance.\textsuperscript{66} Continued NF will identify silenced neurons and large errors in neural activity (previously disregarded as just noise) both of which impair cognitive plasticity and will improve overall performance.\textsuperscript{67} Aware of their neural
status, swimmers may discover abilities to extend oxygen deprivation or corpsmen may have new control of emotions and reduced stigma of lost limbs. Neuro-feedback will not only provide sailors with conscious awareness of the stressful aspects of their profession and assist in developing an individual development plan, but will link to shipboard neuro-treatment to transform degenerative neurons.\textsuperscript{68} External stimuli such as Transcranial Magnetic Stimulation (TMS) applied directly from the NFD to the motor cortex will activate new neurons created from stemcells; stimulate specific brain regions recognized as pertinent to a critical naval task; and will inhibit undesirable neural states such as depression and insomnia.\textsuperscript{69} Through NFD brain adaptation, future mindfulness training, and neuro-pharmacological enhancements the future sailor will fine-tune his career cognitive ability and increase proficiency-focused specialization, opening the possibility to future neuro-machine interaction.

**BRAIN MACHINE INTERFACE**

A stroke-damaged brain is able to receive injury recovery information as functional electrical stimulation (FES) on damaged muscles creates a signal in the brain.\textsuperscript{70} This circuit reconnection relies on neuro-feedback to provide improvements for injured patients.\textsuperscript{71} As early as 2008, NF has been an integral part of many early prostheses and humans have been implanted with sensors capable of transmitting neural signals to machines. Matt Nagle, a paraplegic, was the first human to volunteer for a project to install a neural interface directly to his brain.\textsuperscript{72} This Brain Machine Interface (BMI) project was a success, as numerous paraplegics successfully controlled computer cursors and robotic arms by thought (see Figure 3).\textsuperscript{73}

Although Artificial Intelligence (AI) is touted as the future of autonomous action it will likely not reach the level of human thought or common sense nor understand its own weaknesses.\textsuperscript{74} Future advances in brain mapping\textsuperscript{75} and in neuro-feedback loop are the next steps
to understanding complex neural activity and its integration with autonomous machinery. Theorists hope to build on the important functions of the corpus callosum and translate the intricate cognitive processes to a computer. This BMI would separately process cognitive inputs back to the individual for an increase in brain speed or provide a temporary boost in cognition.76 The future blending of organic BMI and neural training77 such as: automatic access to Argus 2 video feeds, visual context without visual input, and biofeedback-responsive augmented-reality glasses will allow quicker sailor response.78 By combining augmented and blended reality, a sailor with NFD will (similar to allowing his eyes adjust to the dark) conduct a cognitive warm-up prior to assuming his watchstation. This warmed-up sailor will increase his situational awareness collection ability and decision making, while establishing an updated neural status. Drone pilots linked to a BMI will rapidly identify threat targets subconsciously, well beyond the capabilities of current expert operators. Additionally, through NF, these pilots will have enhanced means to cancel tactical orders or control UAV slave systems.79

The introduction of BMI for sensory processing will further produce a capability to interface neural activity with remote operations of external limbs or unmanned vehicles. This technology, in its infancy, has established a baseline for future NFDs to be the tool for translating thought into the control of external objects. Implanted subjects have been able to focus neural activity (associated with hand movements) to grasp items with robotic limbs.80 Studies as early as 2001 resulted in successful NF loops, in which, robotic movement promoted motor skill adaptation. These leaps provided scientific stimulus to explore robotic extensions of the body which include perceived tactile feedback to brain. Neuroscientists have discovered that the brain is capable of not only learning a new NF loop in just a few weeks, but with a proper NFD it can communicate with an exterior limb autonomously across the globe.81
As scientists design more efficient lifesuits and battery powered exoskeletons, the potential of mind-controlled robots is drastically increasing. Through NFD application, sailors will easily employ robotic firefighters to extremely dangerous areas of the ship or submersible divers to extreme ocean depths. A robust NFD, linked to sensory and motor skills will improve intellectual endurance and achieve mental control in remote areas as a complement to unmanned robotics. Advanced weapon employment will employ pilot eye tracking to control multiple platform movements and cross-domain weapons targeting/employment.

Remote operation will benefit from continued holistic BMI approach as naval warriors’ plasticity allows the melding of sensory and motor skill proficiency with enhanced cognitive ability. This interface will grow exponentially beyond 2030 through the balance of collected facts and provide new level of understanding required for superior decision-making. Enhanced molecular signatures may be identified as cognitive markers targeted for future neuro-training as sailors cycle between improved cognitive ability and motor skills to reduce energy consumption. This advantage will provide focused NF training to improve means of multi-tasking, currently not considered feasible. Through continued use of NFD, the development of non-intrusive neural prostheses will provide improved NF and stimulation to normalize abnormal activity during recovery. These brain pacemakers will provide the ability to transmit recordings of enhanced decision-making neural patterns when a complex situation is overwhelming and impairing the sailor’s choices.

**CONCLUSION**

The future application of NFD requires further development in the appropriate means to employ the most effective plasticity. Until the stability-plasticity dilemma is further understood and the ‘critical periods’ of neural integration are opened to adults, specific areas of the brain
may remain shut off.\textsuperscript{89} These eventual developments will lead to NFD’s ability to target weaknesses\textsuperscript{90} and refine naval training to act upon the correct functional neural actions.\textsuperscript{91} As NFD activity is mapped and linked at team level, naval commands will be provided readiness and training programs to address degradations in pertinent categories required for complex operations, such as a short-notice nighttime small boat attack.

On a surface combatant, the TAO will be able to assess the CIC’s mind health and address improvement techniques on the spot to increase focus or ease emotional stress. Beyond the cognitive realm, the advances in ISR capabilities and naval technology will require an advanced sailor processing capability. To assess this capacity, naval commands will require NFDs to assess collection specialist’s baseline sensory skill level, possibly focusing on his Corpus Callosum to not only understand and improve his ability, but ‘plug in’ his processing to computer interface which will provide a hybrid, interfaced neural processing. This new level of attainment creates a new super-thinking sailor, looking for more complex problems to challenge their brain. As the naval leadership employs these enlightened warriors, simple level tasks will now be managed and performed concurrently with other tasks, all from the confines of a reduced-manned ship, located in an austere location, prepared for the next complex operation.

The challenge for naval leaders is to embrace the differences between the varying performances of the brain regions and determine a developmental plan to enrich the areas that NFDs assess as deficient. Evaluating at-sea sensory and motor skill performance quickly and accurately will only be capable by a rapid NF assessment. The NFD will not only establish neural baselines for all sailors onboard, but will lay the foundation for a robust neural developmental plan focused on challenging the brain’s plasticity to improve cognitive ability, sensory processing, and an enhanced brain-machine interface.
ILLUSTRATIONS

Figure 1: “Emotiv” EEG Headset

Figure 2: “NeuroSky” EEG Headset

Figure 1: “BrainGate” with Robotic Arm
END NOTES

1 Axel Visel et. al., “A High-Resolution Enhancer Atlas of the Developing Telencephalon,” *Cell* 152, Issue 4 (February 2013): 895-908 and “First measurements made of key brain links,” *Brown University*, last modified December 4, 2012, http://news.brown.edu/pressreleases/2012/12/thalamus. The cortex processes sensory information from other parts of the brain, such as the thalamus. The primary senses (visual, auditory, touch) are served by regions referred to as visual cortex, auditory cortex and somatosensory cortex. The Cerebrum has 2 parts, first the cerebral cortex which processes information and the basal ganglia which controls movement and is associated with learning. The thalamus is the switchboard that provides info to the PFC and assists in maintaining consciousness. The thalamus inhibits and over time achieves an even state of arousal. With repetition, it becomes weak and further damage can create a coma.


3 “BRAIN Initiative Challenges Researchers to Unlock Mysteries of Human Mind,” The Whitehouse Blog, Last modified on April 02, 2013, http://www.whitehouse.gov/blog/2013/04/02 brain-initiative-challenges-researchers-unlock-mysteries-human-mind. The announcement detailed that a goal is for “researchers [to] produce real-time pictures of complex neural circuits and visualize the rapid-fire interactions of cells that occur at the speed of thought. Such cutting-edge capabilities, applied to both simple and complex systems, will open new doors to understanding how brain function is linked to human behavior and learning.”


6 “Feedback Can Have a Negative Impact on Performance,” Queen Mary University of London, Last modified on August 14, 2012, http://www.qmul.ac.uk/media/news/items/se/82600.html. Too much feedback (+ or -) on complex decision making, makes the decision worse.

7 “Army hopes to have enhanced super troops by 2030,” Foreign Policy Magazine, Last modified on December 17, 2012, http://killerapps.foreignpolicy.com/posts/2012/12/17/the_army_hopes_to_havephysically_enhanced_super_troops_by_2030_or_so. TECOM has acknowledged that enhanced soldier mental ability is an important aspect of future warfighters.

members' accuracy was least effected. Conversely, under extreme conditions, the highest skilled displayed the most output of work, compared to low-skilled military members.  

26 Medical research council, 15. The highest skilled laborers had the least impact on accuracy due to increase in temperature, whereas the highest skilled had most impact on the number of work finished due to increase in heat. (lowest skilled, opposite). Also a study that found that those military members considered the highest skilled unable to maintain a high rate of accuracy when tested to extreme environmental conditions, whereas the lowest skilled members' accuracy was least effected. Conversely, under extreme conditions, the highest skilled displayed the most output of work, compared to low-skilled military members.
and interbrain synchronization and network properties when playing guitar in

recognition and is the topic of many artificial intelligence applications as a hopeful means to emulate brain activity

Freedman asserts that how brain stores and recalls information (not how the brain

memory problem, but not any problems in perception, rule learning, or cognitive function; David H. Freedman et. al.,

Damage to the hypothalamus results in a long-term

to human

Sante Fe Institute Studies in the Sciences of Complexity, (Addison-Wesley: Reading, MA, 1995), 67. Simultaneous

activity occurring in multiple regions of brain during memory recall; not in sequence. As Morowitz describes, a

mere loss of memory does not equate to a loss of perception or other cognitive functions. As he notes, amnesiacs

still learn skills and do not require a declarative memory. Damage to the hypothalamus results in a long-term

memory problem, but not any problems in perception, rule learning, or cognitive function; David H. Freedman et. al.,

Brainmakers: How Scientists are Moving Beyond Computers to Create a Rival to the Human Brain (Simon and

Schuster: New York, NY, 1994), 112. The memory storage and recall process is much more intriguing than the

brain's calculative power. Freedman asserts that how brain stores and recalls information (not how the brain

calculates) will ultimately change society.

Freedman, 88. The ability to reorient new inputs to our longer-term memory is an important aspect of our pattern

recognition and is the topic of many artificial intelligence applications as a hopeful means to emulate brain activity

84-85. Freedman refers to Grossberg's Adaptive Resonance Theory (ART) which pays attention to human
tendency to focus on the familiar parts in a pattern that match our long-term memory and attempting to ignore any unfamiliar (new input) patterns. ART attempts to reconcile through reorienting Artificial Intelligence (AI).

41 Freedman, 181-182. He cites Demmett's finding that numerous input signals are sorted by the brain and used to create or reinforce patterns.

42 Beilock, 54-57. When researching professional speed chess players, Beilock found that they are also good at regular chess. All chess masters have faster reconstruction (scenario) ability, with fewer glances, due to learning of meaningful patterns.

43 Hubert L. Dreyfus et. al., Mind over Machine. (Free Press: New York, NY, 1986), 88. According to Dreyfus, if our brains followed just rules all the time, nothing would be completed, as continual evaluation would exhaust our time. According to Dreyfus, humans "proceed in life using past experience, organizing the way next events show up.”

44 George A. Miller, “The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information,” Psychological Review 63, no. 2 (1956): 81.

45 Sian Beilock, Choke. What the secrets of the brain reveal about getting it right when you have to, (Free Press: New York, NY, 2010), 235-237. Beilock explains that the Prefrontal Cortex (PFC) uses schemas (packets of info that provide expectations of our activities) to guide our focus (i.e. job interview first impressions). We self-measure new inputs with stored patterns (schemas) which guide our attention focus.

46 Hugh Pastoll et. al., “Feedback Inhibition Enables Theta-Nested Gamma Oscillations and Grid Firing Fields,” Neuron 77, no. 1 (2013): 141. This rhythm sometimes quiets certain neurons IOT use weaker and more pertinent ensembles; Both Pastoll and Salazar et. al., note that short term memory transmits through brainwave sync and the oscillations may actually carry visual info. Brain cells do not communicate with each other, but through cells known to reduce electrical activity using this wave rhythm; M. J. Henry et. al., “Frequency Modulation Entrains Slow Neural Oscillations and Optimizes Human Listening Behavior,” PNAS 109, no. 49 (2012): 20095-20100. The brain uses rhythmic fluctuation to prepare for processing upcoming info allowing for prediction, based on upcoming gap (slow wave).

47 L. Gregory Appelbaum et. al., “Stroboscopic visual training improves information encoding in short-term memory,” Attention, Perception, & Psychophysics 74, no. 8 (November 2012): 1681-9. It forced patients to work harder than normal and then have greater memory for up to next 24 hours.


49 J. D. Creswell et. al., “Neural Reactivation Links Unconscious Thought to Decision Making Performance,” Social Cognitive and Affective Neuroscience (2013). Decision making is shown to be impacted by subconscious activity, as distraction and reactivation is occurring, opening new opportunities for learning research.

50 Jonah Lehrer, How We Decide. (Houghton Mifflin Harcourt: New York, NY, 2009), 20-21. In an interview, a prominent soap-opera director explains that due to time constraints and high level of actor rotation, he relies on his intuition when choosing new actors for roles. These regions traditionally associated with bliss and irrational thought and behavior, are now better understood to be important aspects of cognitive function and are viewed in conjunction with chemical-electrical reactions, just as neurotransmitters; David G. Rand et. al., “Spontaneous Giving and Calculated Greed,” Nature 489 (2012): 427-430. Intuitive thinkers are the most-cooperative, while the least-cooperative are not intuitive thinkers.


53 Lehrer, 28-35. During Operation Desert Shield, Royal Navy LT Cdr Riley observed a recognized radar blip on the screen, coming from land, heading towards a US Battleship. Due to the timing and limited vision on the blip, there is no way to rationally ascertain if the blip was a returning friendly aircraft or a enemy, inbound missile. The LT Cdr reacts anyway, initially viewed as a gamble. Gary Klein’s follow-up investigation shows that Riley’s brain caught blip’s late appearance and signaled shut down to dopamine. Riley caught it through experience of watching blips, which were training dopamine predictions. When a single flash of fear activated in Lt Cdr Riley, he reacted.

54 Benedetto de Martino et. al., “Frames, Biases and Rational Decision-Making in the Human Brain,” Science 313 (2006): 684-687. In an fMRI that showed a domain of losses, the amygdala was excited. Those subjects, who did not view domain of losses, still had active amygdala (due to negative emotion) but had a more active PFC role.
Lehrer asserts that this is due to a combination of metacognition and the PFC constantly monitoring our emotional brain.

55 Beilock, 252-253. The PFC includes reappraisal ability and avoids impulsivity. When stress increases, PFC can lose control of emotions and inhibitions.

56 Lehrer, 60, 68-69. When dopamine fires in the brain too late, such as a surprise after a prediction, we experience a rush of dopamine, commonly referred to as the gambler trap. Investors can get trapped into domain of losses which provides a lesson to neurologists, dopamine not designed for randomness, complexity. It is a primitive reward circuit.

57 Dreyfus, 90.

58 Joe Johnson et. al., “Take the First: Option-Generation and Resulting Choices,” Organization Behavior and Human Decision Process 91, (2003): 215-29. A group of handball professionals always initially choose right play (during video freeze); after more time, they would end up picking different, incorrect predictions. Professional handball players, when reviewing screenshots of professional matches and given a short period of time, the players were able to successfully predict the next play. Yet when the players were given more time with the screenshot and afforded an opportunity to analyze options and discuss an optimal (PFC) play, they predicted the wrong play; Paul K. Davis, Implications of Modern Decision Science for Military Decision-Support Systems (Rand Corporation: Santa Monica, CA, 2005), 84-93. As a swim team psychologist, he conducted intervention to address poor performances. When Hap Davis conducted immediate interventions with the team after swim performance errors, pre and post fMRI results showed improvements in amygdala activity and less activity in the motor regions (planning and executing of movements). These findings used neurofeedback to control the swimmer’s focus during performance, so that their PFC did not create paralysis through analysis.


62 Lehrer, xvi, 11. Lehrer asserts that the brain is pluralistic and describing it as rational is a flaw, whereas comparing with the classic Plato’s chariot is a more applicable analogy to the sharing between rationality and emotions; Antonio Damasio, Descartes’ Error. (New York: Penguin, 1995), 43-44. A patient with a tumor that caused him to have no emotion and surprisingly resulted in the man having no decision-making ability. The area of the cortex damaged was responsible for connection between primitive brain (stem and amygdala) to conscious thought. Dreyfus, 64. The dysfunction known as anosognosia impair perception. It depends on analysis and rationality only, and neglects the individual any emotion; Henschaw, 192. In Prosopagnosia (face blindness), the individual’s brain is similar to computer. The man only could see the parts, but not wholeness.


64 Beilock, 58. Professional Musicians have larger Corpus Callosum, the earlier and longer they start playing music in life. When playing, professional pianists have limited PFC activity, they are using emotional mind. Such as the neural mechanism involved with young children who learn to play a musical instrument or multiple languages.

65 Beilock, 130. With regards to balance, Beilock explains that 2 or more regions activated at the same time from same region is much harder to control then 2 regions from separate locations on the brain.
Advanced Ekoskeletons and TEDtalks

Director February 18, Nicolelis presents a neuroscience lecture to TEDMED

Vanderbilt 82 Mukand, 278-279 and computers, avatars, and eventually a robot (located in Japan) with Brain Machine Interface, posted by

Miguel Nicolelis: A monkey that controls a robot with its thoughts. No, specific regions, when correctly identify object (normally in subconscious). This may lead to a future braingate for drone pilots to control

http://www.irishtimes.com/newspaper/sciencetoday/2012/1108/1224326303333.html. Drone pilots brain lights up in


use glasses that turn pages with eye movement present a possible future personnel info management system.

Dr. Nicolelis presents a neuroscience lecture to TEDMED 2012 and details research with test monkeys that control computers, avatars, and eventually a robot (located in Japan) with Brain Machine Interface, posted by TEDtalksDirector February 18, 2013, http://www.youtube.com/watch?v=CR_LBeZg_84.

Mukand, 278-279 and “Advanced Exoskeleton Promises More Independence for People with Paraplegia,” Vanderbilt University, Last modified October 30, 2012, http://news.vanderbilt.edu/2012/10/exoskeleton/. New ekoskeletons and “lifesuits” such as (ReWalk, Monty Reed, Goffer) are developing at an increased rate.
"Damage Control for the 21st Century," *U.S. Naval Research Laboratory*, Last modified in March 2012, http://www.youtube.com/watch?v=z0lO05QdZeg. NRL has a robotic firefighter being led by human director.

Moreno, 230.

Mukand, 97, 319. A post stroke, damaged brain still receives info on recovery (alain kuelin-lang), an electric stimulation at muscle/nerve creates signal in the brain (feedback). This is Functional Electrical Stimulation (FES) discovered in 1998 by Shaheen Handy. Neuroscientists (such as Donoghue, Kirsch, and Leuthardt) are looking to link FES wirelessly with braingate and link BCI patients who have suffered from strokes.


Robert E. Hampson et al., “Facilitation and Restoration of Cognitive Function in Primate Prefrontal Cortex by a Neuroprosthesis that Utilizes Minicolumn-Specific Neural Firing,” *Journal of Neural Engineering* 5, no. 5 (2012). Successfully recorded good decision making brain signal and then playback to brain when impaired (monkeys on cocaine) of which they were able to conduct improved decision making.

Freedman, 84-85. Grossberg's adaptive resonance theory Stability and plasticity dilemma. The dilemma is centered on the stability to learn while retaining, yet plasticity provides us ability to learn unexpected thing.

Henshaw, 225. If plasticity not corrected during children's critical period, the ability is shutoff.

Dreyfus, 113. Computers (AI) don't know their own weaknesses (Chess games) nor do they know Common sense.

Dreyfus, 140. USAF instructors teach a process, but when performing their eyes do different.
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