Cognitive Performance in Operational Environments

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ABSTRACT

Optimal cognition during complex and sustained operations is a critical component for success in current and future military operations. "Cognitive Performance, Judgment, and Decision-making" (CPJD) is a newly organized U.S. Army Medical Research and Materiel Command research program focused on sustaining operational effectiveness of Future Force Warriors by developing paradigms through which militarily-relevant, higher-order cognitive performance, judgment, and decision-making can be assessed and sustained in individuals, small teams, and leaders of network-centric fighting units. CPJD evaluates the impact of stressors intrinsic to military operational environments (e.g., sleep deprivation, workload, fatigue, temperature extremes, altitude, environmental/physiological disruption) on military performance, evaluates noninvasive automated methods for monitoring and predicting cognitive performance, and investigates pharmaceutical strategies (e.g., stimulant countermeasures, hypnotics) to mitigate performance decrements. This manuscript describes the CPJD program, discusses the metrics utilized to relate militarily applied research findings to academic research, and discusses how the simulated combat capabilities of a synthetic battle laboratory may facilitate future cognitive performance research.

1.0 INTRODUCTION

1.1 The Complex Cognitive Environment

During wartime, combatants experience mental and physical demands well beyond those seen in peacetime training environments. During a typical combat deployment, they face stressors such as environmental extremes, muscular fatigue, sleep deprivation, information overload, emotional strain from seeing horrific injuries and death, and anxiety for the welfare of their families at home. Preparing our warfighters to succeed in the most demanding of combat conditions is of foremost importance. We risk, however, increasing the stress on our warriors at all levels by bombarding them with excessive or inappropriate information. As volume and complexity of available information increase, we often equate "more" with "better". This is not necessarily the case. For example, time for decision-making is becoming more compressed. The consequences

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of decisions made by a relatively few individuals impact our strategic interests more profoundly than in the past because of the increased lethality of munitions. We face having more information to process in less time. Unless we find ways to improve perception and cognitive agility, we expose our future forces to greater risk because of the increased technological capabilities of modern military electronic and information systems. Warriors require confidence that their cognitive capabilities are as well developed as their physical fitness. Leaders and followers at all levels need to train and exercise their cognitive processes in order to optimize their judgment and decision-making. As decision-making responsibilities are increasingly distributed to single individuals and small teams, assessment of cognitive performance and provisions for feedback of cognitive readiness become even more important. By creating clear communication and unambiguous standing operating procedures for those needing that information, the foundations for improved performance and decision-making may be strengthened.

1.2 Cognitive Performance, Judgment, and Decision-Making Research Program

Cognitive performance is impacted by stressors intrinsic to operational environments (e.g., sleep deprivation, workload, fatigue, and environmental/physiological disruption). Evaluating the effects of these stressors individually and in combination is critical. The cognitive research effort “Cognitive Performance, Judgment, and Decision-making” (CPJD), is a collaboration among multiple U.S. Army Medical Research and Materiel Command laboratories, U.S. Air Force, U.S. Navy, U.S. Federal Aviation Administration, and National Aeronautics and Space Administration, with the primary goal to sustain, enhance, monitor, and predict cognitive performance of individuals and teams. The military goal, to improve the operational effectiveness of future airmen, soldiers, marines, and sailors, is paralleled by the U.S. Federal Aviation Administration’s goal of preserving aircrew performance, and by the National Aeronautics and Space Administration’s goal of optimizing cognition in the astronaut. The measurement paradigms, e.g., communications, through which operationally-relevant higher-order cognitive performance, judgment, and decision-making can be assessed and sustained in individuals, small teams, and leaders, are applicable across our increasingly complex societal organization. This approach is illustrated nicely by Brannick, Salas, and Prince (1997) with classic observations and findings from several previously studied operational groups.

The CPJD research program (**Table 1**) performs and supports quality research into the development of operational metrics through which network-centric battlefield performance may be assessed, and the mapping of these field-based metrics with battle laboratory data. The program seeks to identify the benefits of safe and effective countermeasures to the effects of fatigue and stress upon cognition, specifically pharmacologic agents that may sustain or enhance cognitive performance. The program also identifies and develops unobtrusive neurophysiologic techniques to monitor cognitive performance, so as to provide advance notification in event of deteriorating cognitive performance, and potentially to activate automated mechanisms to reduce cognitive workload.

Table 1: Organization of the Cognitive Performance, Judgment, and Decision-Making Research Program.

Team	Mission
Operational Processes and Cognitive Mapping	Develops understanding of militarily relevant operational processes, and maps them to battle lab and research laboratory paradigms.
Cognitive Metrics	Identifies, develops, and evaluates different cognitive performance measures for comparison of cognitive processes across multiple research laboratories.
Pharmacological Strategy	Identifies the impact of psychoactive agents (e.g., pharmaceutical fatigue countermeasures; ketamine, SSRIs) upon cognitive performance.
Neurophysiologic Measures and Cognition	Identifies and advances field-deployable neurophysiologic measures to transparently and unobtrusively infer and monitor cognitive performance in individuals performing on mounted and dismounted operational platforms.

2.0 ASSESSING OPERATIONAL PERFORMANCE

Effective cognitive performance during complex ongoing operations in extreme environments is always a challenge. The teamwork between ground and astronaut crew during the Apollo 13 mission, with the whole world watching the dramatic unfolding of an almost fatal space flight successfully return to earth, showed highly effective individual, team, and inter-team cognitive performance (Shayler, 2000).

The Apollo mission was life threatening, yet the ground and astronaut crews had the advantage of both effective communication links and a window of opportunity. Soldiers in the field do not always have the same advantages. Belenky reports of an unfortunate incident during the 1990 Gulf War when two Bradley fighting vehicles were destroyed by friendly fire because of cognitive disorientation by crew in other Bradleys. The crews that inadvertently fired upon their own teammates self reported brief and fragmented sleep over the previous 48 hours. Fortunately, no American lives were lost (Belenky, 2005).

The military battleground, today and in the future, will require the individual soldier to combine courage with higher order cognition processes, including judgment, situational awareness, planning, and effective decision-making. At the same time, the individual soldier works and lives within a multi-person, multi-agent (complex-systems, robotics) team that is networked across both human and robotic systems. Any consideration of cognitive performance in military operations needs to include individual and group cognition processes and factors.

Military operations do not lend themselves to the rigor of science. Surrogate environments that simulate closely actual operational environments may allow mapping of military battle-relevant operational processes to research laboratory and analog paradigms. Additionally, similar simulations and operational surrogate work performed by other relevant government agencies may be leveraged. The Tactile Situation Awareness System (TSAS) and Agent-based Modeling and Behavior Representation (AMBR) Project are examples of military research endeavors relevant to operational mapping. TSAS (McGrath, 2004), using tactile and sensor technologies embedded within flight garments, provides intuitive perceptual information about the operational environment that facilitates better decision-making when navigating aircraft in instrument meteorological conditions. The operational performance improvements can be directly mapped to the signals generated through the TSAS. AMBR focused on developing cognitive and behavioral modeling applicable to operations in global theaters (ref: Air Force Research Laboratory, 2005). AMBR, using the Harvard Medical School's Circadian Performance Simulation Software (CPSS), generates predictions regarding changes in cognitive efficiency as a function of sleep history, circadian desynchrony, and light exposure. These predictions may be mapped directly into operational performance outcomes generated through network-centric battle-laboratory engagements. A National Space Biomedical Research Institute (NSBRI) project, originally led by Megan Jewett and now by Beth Klerman, is developing the CPSS so that it can predict an individual's performance, as well as a group mean performance (personal communication, D. Dean, March 2004; Jewett, Kronauer, 1999; Jewett, Forger, Kronauer, 1999; Mallis, Mejdal, Nguyen, Dinges, 2004; Van Dongen, Dinges, 2003).

Researchers such as the Caldwells (2003), Dinges (1995), and Mallis (2004) also are working on the prediction of performance degradation based on sleep-related fatigue. Their pioneering work shows to take relevant cognitive factors, map out a series of studies that relate to complex hazardous missions such as those found in combat, and develop predictive models of performance. It is time to follow the model of the fatigue researchers and expand model inputs beyond that of sleep-related variables to other relevant factors (e.g., task saturation, information overload, environmental extremes, confinement, stress, resilience, communication, alignment of roles and responsibilities across multi agents, distributed decision-making, teamwork), map these factors to military operations, and develop rigorous and accountable research programs.

Future deliverables focused on cognition in complex operations should first include a prediction of an individual's overall cognitive performance state based on that person's individual baseline. An individualized model would allow prediction of readiness to perform prior to specific cognitive performance task degradation. To develop such a predictive model, the algorithm would include those quantifiable factors known to systematically affect cognition.

A second deliverable would be operationally robust metrics that can accompany the individual into extreme environments without adding an extra burden. Metrics will need to be resistant to environmental stressors, unobtrusive, noninvasive, and, for the military, undetectable. Embedding measures of cognitive functioning into actual required performance tasks would be the least obtrusive and the most specific indicator of effective performance. In an example using unmanned aerial vehicle operators, the cognitive effectiveness of the human remotely directing the robotics could be studied by measures such as ability to maintain course headings, ability to monitor critical systems status, and ability to correctly select and effectively engage weapons systems. Gilliland, Schlegel, and Shehab (Gilliland, 2005) have developed and evaluated relevant quantitative measures of remote manipulator systems on the International Space Station (ISS) and the Space Shuttle that enable appraisal of current skill levels; these same metrics also would allow in-flight readiness-to-perform indicators that could be used prior to executing critical operational tasks (Gilliland, 2005).

The presence of data and voice recording "black boxes" in commercial and military aviation platforms provides information on the executive functioning of cockpit personnel and the mechanical functioning of the engineered system. Use of voice analysis (Lieberman, 2005; Meyerhoff, 2000), optical computer recognition programs (Dinges, in press), or actigraphy (Ancoli-Israel, 2003) are other methods that can be used in the field, dependent upon available technology.

Ideally, cognitively relevant metrics will provide feedback to the operator, and to decision-makers who make personnel assignments and battlefield decisions. At NASA, an operational cognitive screening tool, the Space Flight Cognitive Assessment Tool for Windows (WinSCAT) is used on the ISS to allow the individual astronaut to assess the possibility of a neurological insult; if scores are in a clinically relevant range, results are shared with the ground flight doctor (Kane, 2003). Another portable cognitive readiness tool is the MiniCog (Dingfelder, 2004), available on palm pilot platforms and potentially useful in military settings. The Cambridge Neuropsychological Assessment Test Battery (CANTAB) and the Automated Neuropsychological Assessment Metrics (ANAM) (Kabat, 2001; Roebuck-Spence, 2004) currently are used by the Army for assessment of individual performance. The CANTAB is applied in controlled laboratory settings to link basic science and academic research to militarily relevant tasks. The ANAM is applied in training and field environments, and in clinical assessments, to map laboratory based metrics with actual military performance.

Men and women in the forefront of battle are the military's most valuable and vulnerable asset. They are also least likely to be able to access real time feedback loops or make use of some risk mitigation procedures. Lieberman's work on actigraphy and the development of smart clothing (McGrath, 2004) that can measure related biological sentinels of cognitive readiness are promising avenues for future research into measurement and predictive models.

The individual seldom works alone, however. The area of intra-team cognition has direct relevance to military units working in complex, hazardous environments. The Cognitive Engineering Research on Team Tasks (CERTT) Laboratory, located at Arizona State University East, identifies and studies problems associated with socio-technical systems. The CERTT website defines team cognition, and refers to "an emergent property of teams that results from the interplay of individual cognition and team process behaviors and that underlies team performance" (Arizona State University East, 2005, Cooke NJ, 2005). Social cognitive neuroscience looks at three levels of analyses: social, cognitive, and neural, in an attempt to understand the interplay among social and motivational factors, information-processing, and underlying brain mechanisms (Ochsner, 2001). The intricate world of team dynamics and group decisions needs to be mapped to militarily relevant operations and appropriate research programs initiated.

3.0 COGNITIVE NEUROPHYSIOLOGY AND THE FUTURE WARFIGHTER: MONITORING AND PREDICTING COGNITIVE PERFORMANCE

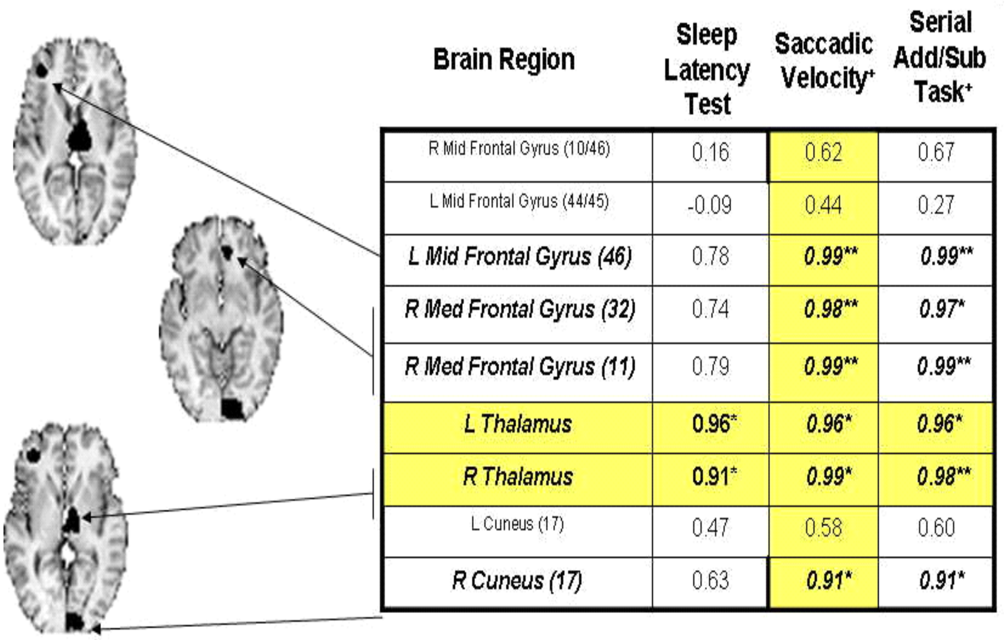
3.1 Cognitive Neurophysiology and Performance

Monitoring cognitive processes is a critical component for sustaining performance in that changes in alertness status, workload, and fatigue component processes may be identified in advance of stressor-induced performance decrements. As outlined by Russo, Stetz, and Thomas (2005), cognitive neurophysiologic studies examine changes in brain function (i.e., neural signals or brain activity) and their relationship to such changes as perceptual and thought generation processes and cognitive performance. Brain regions which mediate Warfighter cognitive performance include the parietotemporal lobules, responsible for visual-auditory-spatial perception; the thalamus, responsible for alertness and integrative perceptual processing; and the prefrontal cortex, primarily responsible for attention, and higher-order functions including working memory, language, planning, judgment, and decision-making. When higher-order pathways and prefrontal regions function normally, risk-taking and decision-making may objectively occur. If these higher-order controls are removed, as can happen during periods of stress and sleep deprivation, judgment and decision-related behaviors may disassociate from the higher-order pathways and instead generate viscerally through the limbic system. Fear and anger, also limbic-system-generated and present on the battlefield, must be controlled lest they overwhelm prefrontal cognitive processes. The impact of extreme stressors on the brain is associated with impairments in cognitive performance.

3.2 Cognitive State and Performance Monitoring/Assessment

Successful control of the battlefield utilizes extrovision, meaning the motivation and mental agility to mine the databanks of the digital battlefield for critical information, over introvision, or the desire to perseverate upon a failing or ineffective internally-generated strategy. Mental agility refers to the ability to rapidly shift from one informational data stream to another, and effectively integrate the relevant components of each into cogent thoughts. On the battlefield, situational awareness reflects the degree of accuracy to which one's perception of the current environment mirrors reality. In order to achieve situational awareness dominance, warfighters must stay focused and alert in a three-dimensional battlespace. Under emerging network-centric warfighting doctrine, command, control, communications, intelligence, surveillance and reconnaissance (C4ISR) data are being distributed to all operational levels, including the individual soldier. Transparent communications facilitate transfer of potentially overwhelming amounts of information to any combat platform (i.e., tank or aircraft) and to all command levels. Consequently, with the increase in sophistication and reliance upon technology, warfighters must anticipate battlefield operations and recognize critical data in order to decide and act more quickly and effectively than the enemy. Real-time monitoring of individuals for cognitive performance capacity via an approach based on sampling multiple neurophysiologic signals and integrating those signals with performance prediction models, potentially provides a method of supporting warfighters' and commanders' decision-making and other operationally-relevant mental processes.

The utilization of advanced neurophysiologic techniques (e.g., EEG) to monitor the signals generated by integrative neural processes, and/or their resultant physiologic outcomes (e.g., movement activity, heart rate indices, ocular responses, vocal expression) as indicators of brain function and behavior, is a major goal of applied cognitive neurophysiology. A positron emission tomography (PET) study has shown that during sleep deprivation, decreased regional brain activity in the prefrontal cortex, thalamus, and occipital cortex (**Figure 1**) correlates with slowing in saccadic velocity and decreased cognitive performance (Thomas et al., 2003). The slowing in saccadic velocity also correlates directly with the impairment in cognitive performance (Russo, Stetz, & Thomas, 2005). These findings support the premise that the physiologic signals generated by, but removed from the actual neural sources, may be viable monitors of both cognitive performance and the integrity of intrinsic neural processing. Altogether, these results suggest that individual neurophysiologic measures may reflect specific aspects of neural processing, and integration of multiple measures might allow understanding of complex higher-order processes.



Brain Region	Sleep Latency Test	Saccadic Velocity$^+$	Serial Add/Sub Task$^+$
R Mid Frontal Gyrus (10/46)	0.16	0.62	0.67
L Mid Frontal Gyrus (44/45)	-0.09	0.44	0.27
L Mid Frontal Gyrus (46)	0.78	***0.99***	***0.99***
R Med Frontal Gyrus (32)	0.74	***0.98***	***0.97****
R Med Frontal Gyrus (11)	0.79	***0.99***	***0.99***
L Thalamus	**0.96***	***0.96****	***0.96****
R Thalamus	**0.91***	***0.99****	***0.98***
L Cuneus (17)	0.47	0.58	0.60
R Cuneus (17)	0.63	***0.91****	***0.91****

Figure 1: Three Different Human Brain Images Showing Areas of Decreasing Brain Activity (annotated in black) Resulting from the Combined Effects of 72 h of Sleep Deprivation. Correlations among Slowing Saccadic Velocity, Increased Sleepiness, and Decreasing Complex Cognitive Task Performance are Shown. Significant Correlations Relate Thalamic Deactivations to Decreased Sleep Latency, Slowing of Saccadic Velocity, and Impairments on the Serial Addition-Subtraction Task. These Correlations Suggest that Objective Sleepiness is Linked to Performance Impairments and to Saccadic Eye Slowing through Thalamic Networks (adapted from Thomas et al. 2003).

When cognitive neurophysiologic monitoring is utilized, an assumption is that the tasks require application of all cognitive processes. Neurophysiologic techniques permit an unobtrusive, transparent (non-interactive) data gathering process that allows monitored individuals to focus all available cognitive reserves on the required performance task. A cardinal feature of many of the second-order cognitive neurophysiologic techniques is that they normally measure involuntary responses, such as EEG, pupil size, or heart rate. Measurement of involuntary responses allows individuals to focus completely on critical tasks, and removes the potential bias of motivation and the demand characteristics of the experiment. In the direct cognitive performance assessment approach, an individual has to concentrate both time and motivation to the cognitive test. The degree that monitoring techniques take into account the individual warfighter's cognitive status (individual vs. group readiness-impairment), and the strength of the relationship between the neurophysiologic measures and operational performance outcomes, are also essential characteristics of a cognitive neurophysiology-based monitoring system.

The potential usefulness of this approach would be 1) to assess the warfighters' cognitive readiness and 2) to predict cognitive performance. The result of assessing cognitive readiness and applying predictive modeling to the changing state of cognitive readiness may be to reduce the occurrence of catastrophic failures and battlefield injury. The ability of monitoring techniques to assess overall cognitive readiness before an actual operation can provide useful logistical information regarding current fitness for duty status, and can provide guidance as to whether fatigue countermeasures should be utilized (such as taking a brief nap or using a pharmacologic strategy). Repeated measures of cognitive indices over time would identify performance trends; and application of computational modeling would provide predictions of decrements in cognitive performance prior to a catastrophic failure. If imminent failure can be identified, then it may be averted by warning the individual or members of the operational unit. If cognitive decline occurs or workload increases, e.g., in an F-16 or Stryker vehicle, automated workload reduction could engage to more closely align cognitive reserves with essential tasks.

The complexity of combat operations, the countless causes of impairments in cognitive performance in the operational environment, and individual differences in response to various combat stressors make it highly unlikely that a single neurophysiologic measure (direct or indirect) will be sufficient to serve as both an indicator of cognitive readiness assessment and a predictor of cognitive performance. Rather, a *system* or combination of unobtrusive monitoring techniques that integrate cognitive neurophysiology and operational performance assessment may be warranted to obtain success.

An ideal neurophysiologic monitoring system applicable for use by the individual warfighter would, by operational necessity, have to meet rigorous hardware and software specifications. For mobile vehicular platforms, which already have power and mounting capabilities, the specifications would be achievable at an earlier stage. In addition to identifying characteristics of a monitor's ability to assess an individual's general cognitive state, predict specific cognitive performance impairment, and be highly predictive of operational performance, other important criteria for the development of an ideal neurophysiologic monitor (**Table 2**) were acknowledged at the recent U.S. Army Medical Research and Materiel Command workshop (Cognitive Performance: The Future Force Warrior in a Network-centric Environment, St. Pete Beach, Florida, 10-12 August, 2004). [Proceedings of this meeting and its follow-on meeting: Cognitive Performance: Force Multiplication through Human-in-the-loop Augmentation, Las Vegas Nevada, 19-21 July 2005, may be found at http://cognitiveperformance.anteon-conferences.com and http://www.momrp.org/35.htm.] Several neurophysiologic measures already meet some of the requirements outlined below, and their development and validation as fatigue assessment and prevention technologies, for example, are underway (Kloss et al., 2002). Wrist-mounted actigraphy, oculometrics, electroencephalography, and voice stress characteristics meet enough of the required specifications to have attracted substantial research efforts. Two of these measures were sensitive to the workload variations presented in the Warship Commander Task, designed as an analog to a Naval air warfare exercise (St. John et al., 2003).

Table 2: General Specifications of an Ideal Physiological Monitor.

- No added weight
- Affordable and cost-effective
- No added power requirement
- Unobtrusive and non-invasive
- Existence of device undetectable
- Transparent in that the monitored individual does nothing to initiate, sustain, or provide the measurement
- Resistant to environmental and physiological artifact (or amenable to real-time artifact removal)
- Relevant feedback provided to monitored individual through workload control feedback or automation
- Information secure from unauthorized individuals

4.0 FUTURE DIRECTIONS: COGNITIVE PERFORMANCE ASSESSMENT IN A NETWORK-CENTRIC AIR MANEUVER BATTLE LABORATORY

An example of a synthetic environment in which simulations emulating performance across multiple command and control levels is the Air Maneuver Battle Laboratory (AMBL). This networked and digitized combat environment contains realistic flight simulators of multiple fidelity levels, command and control systems, and a synthetic 3-dimensional battlespace, and provides an excellent crucible in which to identify techniques to monitor, assess, and predict cognitive performance. The networked air maneuver battle laboratory is an ideal milieu in which to simplify the cognitive environment and clarify communications and display techniques to optimize individual and team performance. Future research would benefit immensely from utilizing the AMBL in studies of stressors and countermeasures.

4.1 The Battle Laboratory Research Environment

Banderet and Russo (2005) note that advances in computers, communications, and information processing have greatly changed the role of the warfighter on the network-centric battlefield.

In network-centric warfare, computers integrate information, acquired from multiple sources, to increase situational awareness of the three-dimensional battle space and create a picture that provides critical and relevant information to all levels of command and control, to include the individual warfighter. Networking occurs through hubs, with information communicated across command posts, vehicles, head/helmet mounted displays, and hand-held computers of individual soldiers. Improved situational awareness yields increased flexibility of mission accomplishment. However, advances in network-centric warfare with improved situational awareness have also created more challenging and stressful conditions for the warfighter (increased operational tempo, greater cognitive workload, and more complex training scenarios). A publication by the National Research Council (1997) evaluating helmet-mounted display technology illustrates how technology sometimes dramatically changes situational awareness, workload, method of engagement, operational capabilities, and training requirements for both individual warfighters and teams. Fortunately, many of the technological advances that make the network-centric battlefield possible also foster methodologies and products that can enable study of the warfighter's performance.

The capstones and predecessors of the network centric battlefield are the network-centric battle laboratories where warfighting techniques are developed (Abbreviated Concept Plan, 2002). According to early Battle Lab documents (Army Regulation 71-32, 1997), Battle Labs are *engines of change* employed by specified proponent to develop, refine, and integrate future operational concepts, capabilities, and architectures within proponent's Future Force developmental mission. Labs are organized to facilitate introduction of new concepts and materiel across currently fielded force's battlefield operating systems and to achieve integrated Doctrine, Organization, Training, Material, Logistics, Personnel, Facilities (DOTML-PF) solutions for Future Force units.

Battle labs conduct simulations and studies as a means to resolve DOTML-PF issues resulting from emerging ideas in support of Future Operational Capabilities. Battle labs use two key questions to drive their efforts: 1) Does the feasibility of a tactical concept and/or advanced technology system warrant further investigation?, and 2) Does the integration of new technologies, coupled with existing or new tactical concepts, provide "military utility" on the digitized battlefield of the future? The battle labs' holistic focus in addressing DOTML-PF issues drives the intent of their efforts beyond just development of warfighting techniques. These battle laboratories are specialized in function, e.g., Air Maneuver Battle Laboratory (AMBL) at Fort Rucker, AL, studies techniques to optimally apply air combat assets. AMBL's mission is to address future concepts from an aviation-centric position and to identify and define issues of interest for the U.S. Army Training and Doctrine Command Futures Center and the Aviation Branch Chief.

4.2 Experimentation within an Air Maneuver Battle Laboratory Environment

Using the AMBL at Fort Rucker as an example, simulated air-land battles are fought by teams of aviators working in concert with ground forces within a synthetic environment that creates future warfighting issues. The war game participants are provided details of the capabilities and organization of enemy forces, strength and configuration of friendly forces, guidelines as to the use of ordnance, and mission objectives. Centers such as AMBL provide an environment for the realistic study of cognitive performance in a simulated combat theater using future technology prototypes.

Two computer systems essentially create and manage evolution of the war game: The Mobile Command and Control Computer (MC2) captures both verbal and written communications and provides the mechanism for issuance of combat related orders. MC2 is a prototype command and control tool that integrates various information sources in a common operational picture (COP) while at the same time allowing sharing of information via multiple communication paths. The second computer system is the Advanced Tactical Combat Model (ATCOM) simulation. ATCOM portrays the synthetic combat environment and allows for combat interactions to be conducted. These combat interactions are converted to digital message traffic that "stimulates" the MC2 common operational picture.

From the role player's perspective, the common operational picture shows in approximately real-time the field outcomes as combat orders are executed. MC2 provides commanders in the network with up-to-date information regarding numbers and condition of combat assets, and allows them to query the status of their units. Commanders and staff, through potential future upgrades to MC2, may be able to query the overall health and cognitive status of their troops during sustained or continuous tactical play. Unit strength indicators (now assessed primarily by the status of functional aircraft), ordnance, and equipment, could be augmented by the status of human assets. The ATCOM computer system displays integrated battle outcomes on a flat-screen monitor using a specific overlay, to represent the outcome for a particular data type. The metrics collected and presented include number of enemy destroyed, degree of destruction (partial versus total), and changing battle conditions. Varied information (data) can be collected and stored by the ATCOM computer system. Having a data collection capability provides analysts an important opportunity to assess critical performance measures.

4.2.1 Techniques to Study Team Performance

The effectiveness of small team performance of both leaders and operators may be studied in the battle laboratory. As in real life, command groups are physically distanced from the operators executing the commands. The cues that prompt configuration changes and factors that influence the command staff to self-organize may be assessed by their communication equipment utilization, interpersonal distance measurements, the information communicated, and the recipients of the information. For players executing the missions, information may be captured that indicates successful formation of aircraft for movement towards and engagement of the enemy, selection and utilization of appropriate ordinance, and extraction of assets from the combat location.

Small team interactions among command and staff elements may be measured in a battle laboratory environment using interpersonal interaction metrics. One such mechanism for capturing individual interaction metrics is the Sociometer (Media Laboratory, Massachusetts Institute of Technology, Cambridge, MA) (Choudhury & Pentland, 2003; Eagle & Pentland, 2003). The Sociometer collects information regarding the distance of the wearer to other people nearby (most appropriate for teams whose relative positions are not static or predefined), patterns of speech, and levels of activity. The Sociometer is worn on a person's shoulder and includes several electronic sensors; the entire unit with batteries is approximately the size of a small personal digital assistant. Data analysis allows determination of the proximity (defined by distance or frequency of contact) of a person to others across time. Proximity, defined by the frequency of communications or the distance between people when communicating, may be assessed for the emergence of patterns correlated with successful outcomes. Speech utterances may be synchronized along a common timeline, providing information on the dynamics and patterns of communication, without regard to the specific information conveyed.

Simulation of many events (probes) are reproducible within a battle laboratory environment. Within these simulations, metrics may be identified that allow us to capture information about the cognitive readiness of the pilot, the staff, and the leaders. The metrics, such as continued flight heading or choice of munitions, could be captured unobtrusively, without interaction or awareness by the observed warrior. These metrics could be correlated to an individual warrior's cognitive neurophysiology, that is, correlated to components of actual brain function. Through static and repeated measurements, current cognitive performance capability and predictions of future cognitive readiness may be determined.

5.0 CONCLUSIONS

In summary, combatants during wartime experience mental and physical demands well beyond those seen in peacetime training environments. Cognitive performance is a function of the impact of stressors intrinsic to operational environments (e.g., sleep deprivation, workload, fatigue, and environmental/physiological disruption). Evaluating the effects of these stressors individually and in combination is critical to deriving the correct predictive equation. Through measurements of cognitive neurophysiology, current cognitive performance capability and predictions of future cognitive readiness may be determined.

Militarily relevant cognitive research occurs in university-based academic environments, military laboratories, and industry facilities. Linking the research performed in this broad research arena may be accomplished by a common metric and standard paradigms. The common metrics used by the CPJD program include the CANTAB and the ANAM. The CANTAB links academic research into basic military research, while the ANAM links basic military research to applied field studies.

Real-time monitoring of individuals for cognitive performance capacity via an approach based on sampling multiple neurophysiologic signals and integrating those signals with performance prediction models, potentially provides a method of supporting warfighters' and commanders' decision-making and other operationally-relevant mental processes.

The networked battle laboratory, with network simulators of multiple fidelity levels, command and control systems, and a synthetic 3-dimensional battlespace, may provide an ideal environment in which to identify techniques to monitor, assess, and predict cognitive performance. The battle laboratory provides a promising milieu in which to simplify the cognitive environment, clarify communications, and evaluate techniques to optimize cognitive performance.

6.0 U.S. DEPARTMENT OF DEFENSE DISCLAIMER

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