Military Cognitive Performance and Readiness Assessment Initiative

Final Report

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Working Group

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Executive Summary

In March 2016, the Military Operational Medicine Research Program (MOMRP), Medical Research and Materiel Command (MRMC) Program Area Director (PAD) initiated an effort to provide recommendations for a synchronized approach for assessment of Warfighter cognitive performance and readiness within military training and operational environments (termed the Cognitive Performance and Readiness Assessment Initiative, CPRAI, and referred to as the Initiative below). A Working Group was convened, consisting of subject matter experts (SMEs) from the U.S. Army Research Institute of Environmental Medicine (USARIEM), Walter Reed Army Institute of Research (WRAIR), and the U.S. Army Aeromedical Research Laboratory (USAARL).

Initial tasks for this Initiative were aimed at establishing the current state of science pertaining to Warfighter cognitive performance assessment. Information regarding assessment practices, research findings and needs were collected from SMEs within MOMRP [and later across the Department of Defense (DoD)] and from a review of the research literature. Analysis of information obtained through these sources revealed four key gaps in current cognitive assessment approaches and capabilities that have contributed to limited progress in providing effective, targeted solutions to leaders and Warfighters to sustain and enhance cognitive health and performance within military training and operational environments[1]. **In short, the goal of determining Warfighter cognitive state and predicting performance under training or operational conditions has not been achieved.** Specifically, these gaps include:

- Lack of empirical evidence linking performance on cognitive assessments to military-relevant performance standards coupled with a poor understanding of the cognitively-demanding elements of military job requirements and related tasks and standards.
- Lack of cognitive tools and metrics with adequate sensitivity, specificity and ecological validity to predict or detect changes in military task performance before operationally meaningful degradation occurs.
- Lack of sufficient/effective coordination of communications regarding cognitive performance assessment among MRMC researchers and non-MRMC collaborators.
- Need for improved coordination of communications between the DoD research and operational communities.

To close these gaps, the Working Group provides a Research Roadmap (or Program of Research) that will facilitate a coordinated, state-of-the-art approach for cognitive function assessment and prediction of Warfighter performance within real-world military training and operational settings.

Key deliverables for this proposed Program include the following:

1) Operationally defined cognitive proficiency standards for select individual military job tasks.
2) Validated cognitive measures for evaluation of Warfighter performance on select military job tasks (common core of tests and/or data elements).
3) Validated metrics for assessing diminished and improved performance on select military job tasks.
4) Advisory board of SMEs to provide input to military leadership regarding cognitive health (readiness) in relation to assessment and performance standards.

[1] The phrase 'military training and operational environments' is meant to describe inclusively all aspects of the active military life cycle [i.e., recruit training, schoolhouse instruction, training exercises (e.g., garrison, live fire exercises, National Training Center exercises), and deployment (for humanitarian, peacekeeping, as well as combat operations)].

Introduction

Warfighters are required to perform a diversity of tasks across military training and operational environments[2]. Optimal execution of these military tasks requires ongoing coordination of physical and cognitive resources to meet the common and unique demands presented by both task and setting. These resources are adversely impacted by internal and external threats, such as sleep loss, physical stressors (e.g., use of Mission-Oriented Protective Postures or MOPP gear), injury, environmental hazards and stressors (e.g., heat, cold, altitude, chemical threats), changes in nutritional/hydration status, and social/emotional stress. The nature of the military task itself also may strain physical and cognitive resources, such as when performing mundane, repetitive job activities, or highly complex tasks that amplify cognitive load. The effects of degraded physical resources –increased risk of accidents and injuries, reduced individual and unit readiness and effectiveness, and decreased likelihood of meeting mission or training objectives – can be objectively evaluated within military training and operational environments using measures that are fairly well established and implemented across all branches of service (e.g., time to complete a 12 mile ruck march or the ability to load an artillery round onto an ammunition rack). However, the impact of degraded cognitive function on the ability to successfully complete military tasks or meet mission objectives is less clear, and validated tools for objective assessment of the cognitive aspects of performance outside of a laboratory setting are lacking. Impaired ability to perform work or training tasks adequately, let alone optimally, has significant consequences for the Warfighter and the unit. Thus, it is imperative **to establish a path forward to achieve better understanding and to assess the mechanisms that underlie Warfighter performance**. Here, in this Final Report, we make recommendations for assessment of Warfighter performance from a cognitive perspective.

In March 2016, the Military Operational Medicine Research Program (MOMRP), Medical Research and Materiel Command (MRMC) Program Area Director (PAD) initiated an effort to provide recommendations for a synchronized approach for assessment of Warfighter cognitive performance and readiness within military training and operational environments (termed the Cognitive Performance and Readiness Assessment Initiative, CPRAI, and referred to as the Initiative below). To accomplish this objective, a Working Group was convened, consisting of subject matter experts from the U.S. Army Research Institute of Environmental Medicine (USARIEM), Walter Reed Army Institute of Research (WRAIR), and the U.S. Army Aeromedical Research Laboratory (USAARL).

This Final Report provides an overview of the approach taken by the Working Group to a) identify existing or emerging tools that are or can be used to evaluate or predict Warfighter cognitive performance within military training or operational environments and b) recommend a Research Roadmap for a synchronized approach for Warfighter cognitive performance and readiness assessment within diverse military environments. It is understood that the proposed

[2] The phrase 'military training and operational environments' is meant to describe inclusively all aspects of the active military life cycle [i.e., recruit training, schoolhouse instruction, training exercises (e.g., garrison, live fire exercises, National Training Center exercises), and deployment (for humanitarian, peacekeeping, as well as combat operations)].

Roadmap, while specifically focused on the medical aspects of Warfighter performance and readiness assessment (e.g., those aspects that directly impact Warfighter physical, cognitive, and mental health and injury risk), fits within the larger scope of current efforts across the DoD aimed at providing solutions for human performance assessment, optimization, and enhancement. It is intended that this Roadmap provide a path forward to advance Warfighter performance assessment capabilities that is synchronized across MOMRP laboratories, as well as coordinated with relevant DoD programs and efforts.

Chapter 1 of this Final Report provides a detailed description of the Initiative's primary objectives and the approach taken to address these objectives.

Key findings from semi-structured surveys of researchers within MOMRP and across DoD, as well as an extensive review of the research literature, are summarized in **Chapter 2**.

Critical Gaps in cognitive assessment capabilities for Warfighter cognitive performance assessment are detailed in **Chapter 3**.

Finally, recommendations and a Research Roadmap outlining a coordinated Program of Research o close identified gaps and to establish common data elements for inclusion in future research are presented in **Chapter 4**.

Chapter 1. Primary Objectives and CPRAI Approach

The first objective of this Initiative was to identify *tools and approaches*, either those that currently are in use or other emerging technologies, to provide objective, sensitive and, ideally, specific measurement of the cognitive components of performance that mediate or modulate how well a Warfighter is able to complete his or her work tasks or mission objectives.

The second objective of this Initiative was to propose a Research Roadmap for a synchronized (across laboratories and/or programs) approach for Warfighter cognitive performance and readiness assessment within diverse military environments (e.g., operational, training, garrison settings). A key goal of this Research Roadmap is to establish a core set of tools or metrics providing a foundation of ***common data elements*** that will facilitate coordination of research efforts and comparison of findings across studies moving forward. The approach taken by the Working Group to achieve these objectives is described in detail below.

A two-phase approach proposed by Working Group Coordinators at USARIEM was approved by MOMRP PAD for completion of Initiative tasks across an 18 month period. The Timeline for Working Group activities is presented in **Table 1**.

Table 1. Initiative Timeline (01 April 2016 – 30 November 2017)

<table>
<tr><th colspan="2">Objectives</th><th>Months</th><th>Task</th></tr>
<tr><td rowspan="8">Phase I</td><td rowspan="6">Assemble primary working groups and initiate information collection procedures</td><td rowspan="2">1-2</td><td>Identify initial USARIEM support team and potential Working Group members</td></tr>
<tr><td>Develop survey/interview instrument to query researchers regarding use of cognitive assessments in their studies, to include specific assessments used, military-relevant environment/setting in which they were used, and reliability/validity of the assessments (results).</td></tr>
<tr><td rowspan="3">3</td><td>Distribute survey to USARIEM investigators</td></tr>
<tr><td>Compile USARIEM survey responses, initiate data input procedures; Interview survey responders for further clarification of responses, as needed</td></tr>
<tr><td>Coordinate and distribute survey to MRMC investigators (WRAIR, USAARL, etc.)</td></tr>
<tr><td>4-5</td><td>Compile survey responses, continue data entry procedures; Interview survey responders for further clarification of responses, as needed</td></tr>
<tr><td rowspan="2">Recommend cognitive assessment tools/approaches (toolkit) from existing tools/approaches that have been validated for</td><td>6</td><td>Assemble Working Group (8-10 max)</td></tr>
<tr><td>6-9</td><td>Convene Working Group to (reaching out to Stakeholders across DoD as needed):
- Summarize cognitive assessments currently in use in military environments
- Summarize the reliability/validity of these instruments</td></tr>
</table>

	use within military-relevant environments and for evaluation of performance of military personnel		- Summarize the environments in which these instruments are being implemented and in what way(s)/for what purpose they are being implemented - Identify gaps/needs in assessment of cognitive performance within operationally-relevant environments - Identify recommended cognitive performance tasks based on current knowledge/tests available
		10-12	Convene Working Group to draft Interim Report
			Vet Interim Report and cognitive performance assessment recommendations through select stakeholders
			Provide Interim Report to PAD
Phase II	Propose the way- ahead (Roadmap) for the execution of an integrated research approach to address gaps by identifying/developing novel and/or emerging cognitive assessment strategies for use in future operationally-relevant environments	13-21	Convene Working Group (reaching out Stakeholders across DoD as needed) to: - Make recommendations for the use of existing or to-be-developed cognitive assessment instruments and metrics to address these gaps (e.g., Warfighter performance assessment toolkit). - Recommend an implementation approach to address gaps in cognitive performance assessment capabilities within operationally-relevant environments

Phase I of the Initiative began on 01 April 2016 and ended 31 March 2017. Working Group efforts in this Phase focused on summarizing the current state-of-knowledge regarding cognitive performance assessment within military settings to include simulated military relevant scenarios (e.g., flight simulators, altitude chamber, etc.).

1. To begin, a semi-structured survey (**Appendix A**) of investigators at USARIEM, WRAIR and USAARL was conducted. Investigators were asked to provide input regarding the cognitive assessment tools and approaches they have used in their research to evaluate cognitive performance within military operational (or simulated operational) environments or to determine cognitive status associated with military relevant conditions/exposures. Examples of assessment tools or approaches examined in the survey included:
    a. Cognitive measures (e.g., measures of memory, attention, judgment and decision making)
    b. Brain imaging/neurophysiological/electrophysiological measures [e.g., magnetic resonance imaging (MRI), functional magnetic resonance imaging (fMRI), magnetic resonance spectroscopy (MRS), positron emission tomography (PET), functional near-infrared spectroscopy (fNIR)], electroencephalography (EEG),]
    c. Neuromotor function (e.g., reaction times, finger/hand dexterity, eye tracking, other modalities)

d. Physiological measures that can predict of cognitive states and military performance (e.g., cardiac measures, respiratory rate, electromyography, skin conductance, temperature, stress hormone levels, etc.)

Points of Contact (POCs) at each MRMC Laboratory were asked to query investigators at their sites for responses to following four questions:

a. In evaluating/predicting cognitive performance in your research, which instruments have you found to be most useful/valid?
b. In what settings were these instruments used (laboratory study, field study)?
c. What do you feel are significant gaps/needs in the area of brain health and performance assessment?
d. What would be most helpful to you in your research?

Investigators were also asked to provide information regarding their previous/current research, to include the following information:

a. Type of study (field/laboratory/database)
b. Study Objective(s)
c. Instruments used
d. Whether or not the instrument was new or previously developed/published
e. Cognitive test findings/results

2. In addition to peer-reviewed manuscripts and Technical Reports provided by participating Investigators at each laboratory, the USARIEM support team conducted reviews of the published literature to include peer-reviewed manuscripts, abstracts/conference proceedings, and Technical Reports pertaining to evaluation of cognition in military personnel within military-relevant settings or undergoing military-relevant conditions/exposures across all branches of service. An overview of cognitive measures identified as part of literature reviews and investigator inputs is provided in **Appendix B**. Although a large number of research documents were identified as part of this search (more than 200), approximately 125 articles met specific search criteria parameters specifically involving assessment of cognitive function within military operational settings and/or use of cognitive assessment measures/metrics to predict/evaluate of Warfighter performance on military-relevant tasks. The Appendix B overview is not meant to be exhaustive, but rather provides an array of measures meeting search criteria that fall within and across broad cognitive domains of function.
3. On 12 January 2017, members of the Working Group convened at USARIEM to review and analyze information obtained as part of Phase I information gathering activities. As part of their review and analysis, Working Group members identified key gaps in the DoD cognitive assessment capabilities and developed recommendations for addressing these gaps. In addition, the Working Group began reaching out to stakeholders across the DoD for additional input. A summary of relevant findings from Phase I activities and

the gaps identified by the Working Group were provided in an Interim Report delivered to the MOMRP PAD in March 2017.

Phase II of the Initiative began on 01 April 2017 and concluded with the Final Report submitted 30 Nov 2017. The primary objective of Phase II activities was to develop and provide recommendations for an integrated research program to address cognitive assessment strategies, to include existing tools as well as novel/emerging approaches, for use in future military-relevant environments. As part of this effort, Working Group Coordinators at USARIEM distributed the Interim Report of the Working Group to stakeholders across the DoD (in March and August 2017) for feedback and input regarding identified assessment gaps and recommendations for closing those gaps. A second and final in-person meeting of the Working Group was held in Bethesda, MD on 25 September 2017, with the primary goal of drafting a Research Roadmap to address the identified gaps. A draft of the Final Report of the Working Group was circulated to key stakeholders (**Appendix C**) in November of 2017 for comment.

Chapter 2. Summary of the Current State of Research

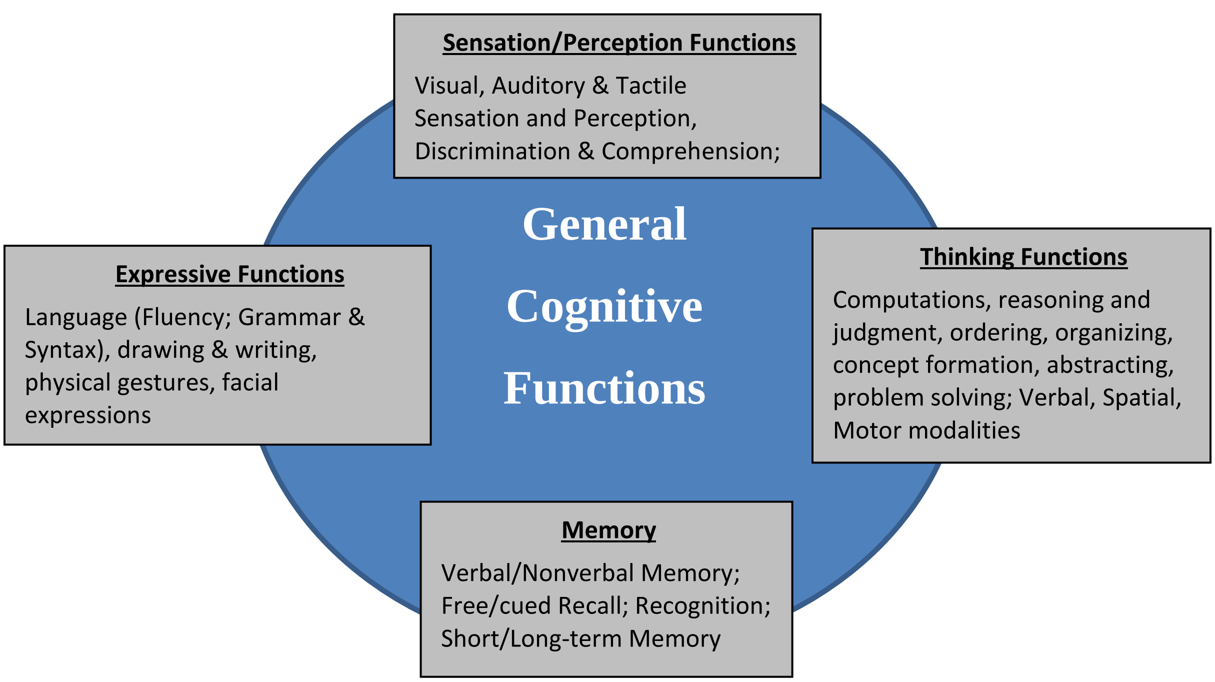
The Initiative described in this Final Report builds upon decades of research aimed at improving and advancing cognitive performance assessment in military training and operational environments. Here, we begin with an overview of cognition and its assessment within research settings. Next, we provide a review of previously organized efforts (Working Groups and Committee activities). Finally, we explore published research addressing cognitive performance assessment within diverse military (or military-relevant) settings. This review is not intended to be exhaustive, but rather it is designed to provide a broad and representative overview of the current state of military cognitive performance assessment.

Cognitive Assessment Overview

Cognition is defined as a system of mental processes by which information (verbal, acoustic, tactile, visual, olfactory) is **received** (sensation and perception), **retained** (learning and memory), **manipulated** (thinking), and **expressed** (verbal, gestural, and facial communications or expressions; see **Figure 1** for further detail).

Core cognitive functions are supported by several higher order functions, including executive function, attention, and working memory. Executive control functions sub-serve volitional, goal-directed behaviors and adaptive responding to novel, ambiguous, or complex stimuli or situations (e.g., strategic planning, reasoning, inhibitory control; Lezak et al. 2012, Hughes 2013).

Figure 1. General Cognitive Functions



The attention system alerts the individual to important information through vigilance and activation of cognitive activity, orients the individual to relevant elements in the sensory environment, and supports executive processes to maintain behavioral control to achieve an intended goal and resolve conflict among competing alternatives (Lezak et al. 2012, Petersen and Posner 2012). Working memory, which is important for reasoning and decision making, is an active process in which information is held temporarily for processing. All of these functions are intimately linked to perform core cognitive functions and higher order processes such as decision making. One model of decision making used by the military is the *OODA loop*: observe, orient, decide, act, and then start again.

Today, cognitive function testing utilizes paradigms that were developed and refined soon after World War I. In general, these paradigms rely upon a trained clinician or technician to administer a standardized assessment protocol (see Gregory 2004, Lezak et al. 2012). The tests vary in their use of props, such as colored blocks for block design tests, and are typically either paper and pencil tasks (for example, connecting numbered circles on a sheet of paper with a pencil or drawing a clock face) or question-answer format. Computer-administered tests and test batteries [e.g., Immediate Post-Concussion Assessment and Cognitive Test (ImPACT), Defense Automated Neurobehavioral Assessment (DANA), Automated Neuropsychological Assessment Metrics (ANAM) Military battery] are increasingly common and are frequently used for field-based assessments of general cognitive state or assessment of sports-related concussion. Computer-based test administration has several advantages over traditional examiner-administered tests. These include portability, elimination of examiner-related variations in test administration, and flexibility for testing individuals or groups. In addition, computer-based testing provides a more reliable and accurate assessment of examinee reaction times than can be achieved by examiners recording responses using a stop watch. The speed with which an individual responds to a given stimulus (i.e., response time) is a common outcome measure on many tasks that is governed by a number of factors. Responding too quickly may be an indicator of impulsivity while slowing of response times may reflect physical and neurological injury or illness. Computer-administered cognitive assessment affords greater ability to detect subtle changes in reaction time that may be more typical of healthy, non-clinical populations than for individuals with brain injuries or other neurologic/psychiatric disease processes (Friedl et al. 2007). Indeed, subtle decrements in reaction time are increasingly believed to represent an early marker for stress- and age-related cognitive decline (Salthouse 1996). Finally, computer-based testing obviates the burdensome requirement that a trained provider/expert be present to collect relevant data, once initial instruction has been administered (Friedl et al. 2007).

The selection of cognitive tests for administration in a given research protocol is generally guided by the specific research questions being addressed in the study (as certain tests have been validated and are more appropriate to use when examining specific hypothesized cognitive performance abilities) and coupled, to some degree, with the individual investigator's familiarity with available assessment tools. Often, researchers have a standard set of tools that they administer across studies within their laboratories and each researcher or laboratory may have his/her own assessment battery or approach. While this approach facilitates comparison of research results across studies within a particular group of investigators or laboratory, it does not facilitate comparison of findings more broadly, across laboratory settings. Utilization of common metrics, or common data elements, facilitates meta-analytic studies across laboratories. However, this approach is ultimately dependent on the availability of appropriate, validated tools for use in military settings.

Considerations for Cognitive Test/Battery Selection

Selection of tests or technologies for evaluation of cognitive function requires consideration of the psychometric properties of individual tests, the availability of appropriate reference data for a given test, and the conditions in which assessments will be conducted (see Proctor and White 1990, White and Proctor 1992).

Psychometric Considerations. The reliability and validity of individual assessment tools is generally considered when selecting tests for inclusion in a research protocol. For repeated assessments, the effects of practice (due to repeated task exposure) on performance outcomes also must be taken into account. For measures that are scored or evaluated by external raters, interrater, as well as intrarater, reliabilities should be evaluated and reported. Distribution of test scores is of particular concern when evaluating performance outcomes in healthy, fit volunteers. A continuous range of scores is desirable, especially when modest shifts in performance are expected. Within this range, a reasonable “ceiling” and “floor” for the given research sample is also important so as to prevent artificial restriction in range of scores across the available score distribution, which would limit the precision and sensitivity of statistical predictions. Finally, it is essential that tests used to evaluate performance in real world settings be validated for such purposes. That is to say, cognitive function measures that are used to predict performance on a particular job task need to be evaluated under a range of conditions in which the particular job tasks are completed in real-world settings. Concurrent measures of performance effectiveness and efficiency, such as physiological and self-reported measures of effort and performance, provide an important source of concurrent validation for measured cognitive function outcomes.

Reference Data. Appropriate reference or normative samples are important to contextualize performance outcomes relative to the performance of one’s peers (Haran et al. 2016). This helps to define both “normal” performance as well as performance falling outside the “normal range”, whether that performance is considered it exceptional or impaired. Reference samples should be representative of the population of persons under consideration, including appropriate range of age, education, socioeconomic status, sex, and ability levels. However, the best predictor of an individual’s own performance is his/her past performance. Thus, whenever feasible, individual baseline performance measures should be collected.

Research Setting. Studies conducted in laboratory settings offer considerable control over a variety of stressors and hazards that occur in real-world military training or operational settings. Factors such as environmental conditions (e.g., temperature, altitude, solar load, wind speed, air quality), occupational chemical exposures (e.g., fuels, degreasing agents, cleaning agents, lead), sleep schedules, nutritional/hydration needs, social-emotional stressors, and others can be manipulated with relative precision. These controlled conditions are often ideal for isolating the effects of individual stressors or hazards on human performance outcomes. However, such conditions often lack ecological validity. Thus performance measures validated in the laboratory may not provide valid assessment of performance outcomes in real-world settings. Military training and operational environments present greater challenges for assessment of cognitive function than those conducted in laboratory settings. In such environments, environmental conditions may be too harsh for use of certain assessment tools. Thus the ruggedness of the instruments needs to be considered. Austere settings also may lack sufficient power needs for non-battery-operated assessment modalities (i.e., computer assisted tasks). Other considerations for field-based assessment batteries include the amount of time needed to conduct assessments, particularly when assessments are made during training or operational operations. In such cases, limited duration assessment batteries are preferable and assessments that do not interrupt or alter ongoing mission or training critical activities, either leveraging performance outcomes occurring naturally as a result of a given activity (i.e., shot placement and timing in a marksmanship task) or tasks embedded into military activities for evaluation purposes, are highly desirable. Finally, in austere environments with limited support staff, tests that are “self-administered”, such as computer-based assessments or applications, or other approaches that eliminate the need for on-site technical or clinical staff (e.g., measures that are “embedded” in Warfighter tasks), are highly recommended.

Past DoD Working Group Efforts

Previous efforts within the DoD to provide improved assessment capability related to cognitive performance and readiness include a number of working groups and committees. Among these, the Joint Working Group on Drug Dependent Degradation in Military Performance (JWGD3 MILPERF) was formed in the early 1980s to provide metrics for evaluating the effects of chemical defense pharmaceuticals on cognitive performance (Reeves and Thorne 1986). The JWD3 MILPERF effort culminated in a collection of tasks called the Unified Tri-Service Cognitive Performance Assessment Battery (UTC-PAB) (Reeves and Thorne 1986). The work of the JWGD3 was later carried on through the Office of Military Performance Assessment Technology and in 1984, extended the application of the UTC-PAB beyond chemical defense antidote exposures to include a more diverse array of operational exposure scenarios (Schlegel et al. 1992, North Atlantic Treaty Organization 2008).

A number of cognitive assessment batteries evolved from the UTC-PAB and related research efforts. These include the Walter Reed Performance Assessment Battery (WRAIR PAB) (Thorne et al. 1985), the Automated Neuropsychological Assessment Metrics (ANAM) (Center for the Study of Human Operator Performance (C-SHOP) 2007) and more recently, the Defense Automated Neurobehavioral Assessment (DANA) (Lathan et al. 2013). Similarly, the Criterion Task Set (CTS) (Shingledecker 1984) was developed by U.S. Air Force researchers as both a measure of human performance and a metric for evaluating the reliability and sensitivity of mental workload tasks. In addition, the Performance Evaluation Tests for Environmental Research (PETER) program was initiated by U.S. Navy researchers to identify a set of measures for evaluation of environmental factors on human performance outcomes (Bittner et al. 1986). The Navy effort yielded a set of 30 measures recommended for use in environmental research and highlighted the need for establishing clear psychometric criteria for applications involving repeated assessments. Working in parallel with the JWGD3 was the Committee on Military Nutrition Research that initiated a Cognitive Testing Methodology Workshop (Committee on Military Nutrition Research 1984). Although the focus of this workshop was to identify cognitive assessment metrics with sensitivity to nutritional deficits, the Committee recognized the need for laboratory-based cognitive assessments that predict Soldier performance on military-relevant tasks.

More recently, researchers from the Army Research Laboratory and NTI Inc. developed the Army Cognitive Readiness Assessment (ACRA), intended to provide an adaptable toolkit based on common cognitive tasks that could be tailored to the specific requirements of Soldiers within a given military occupational specialty (MOS) (O'Donnell et al. 2005). Although the ACRA was designed to improve upon limitations of traditional test batteries for assessment of cognitive performance in operational settings, published research using this battery is, to our knowledge, not yet available.

Building upon the collective working group efforts from the 1980s and 1990s, MRMC initiated the Cognitive Performance, Judgment, and Decision-Making Research Program (CPJDRP) to assess and improve cognitive performance among Warfighters in operationally-relevant settings (Thomas and Russo 2007). As part of this program, the Neurophysiological Measure and Cognition Focus Team (NMCFT) was charged with developing physiological sensors to monitor cognitive status (Thomas and Russo 2007). The CPJDRP culminated in two workshops (one in 2004 and another in 2005), the efforts of which are described in a special issue of *Aviation, Space, and Environmental Medicine* (May 2007). However, momentum for the CPJDRP/NMCFT appears to have dissipated shortly after this time. In 2013, the Consortium for Health and Military Performance convened to discuss and develop a set of tools to standardize a range of Human Performance Optimization (HPO) metrics, to include measures of cognitive performance. The committee identified and ranked commonly used cognitive metrics based on their validity and reliability, and discussed ongoing challenges to address in the future. Among the recommendations made by this working group was the need for a “neurocognitive toolkit” using appropriate and established psychometrics to assess Warfighter cognitive performance both acutely and over multiple assessment sessions (Nindl et al. 2015).

In April 2014, the System for Health Directorate was tasked by the Army Surgeon General to evaluate brain health and cognitive performance under the auspices of the System for Health and Performance Triad. The Brain Health Consortium was formed, falling under the System for Health, within the Health and Wellness Directorate under the G/357, Army Medical Command (MEDCOM). Efforts to develop a program addressing a comprehensive range of issues related to brain health and cognitive performance, including efforts aimed at promoting new and emerging technologies to assess and optimize cognitive performance, have been ongoing. However, this program has yet to be fully implemented and integrated within the System for Health and Performance Triad.

Laboratory-based Studies

One of the primary objectives of this Initiative is to identify field-based cognitive assessment tools and approaches used to evaluate Warfighter performance in training and operational environments. From laboratories at WRAIR, USARIEM, and USAARL alone, more than *65 peer-reviewed publications* and Technical Reports were identified that met search criteria. Of the studies identified during Phase I of this Initiative, most (~70%) were conducted under controlled laboratory conditions. Such studies form the foundation upon which assessment of Warfighter performance in military training and operational settings is often based. Therefore, a brief overview of laboratory-based research that includes cognitive performance assessment is provided below. The review article by Nindl and colleagues (Nindl et al. 2015) also provides a list of cognitive assessment approaches and psychometric properties selected for their application in HPO-related research that are relevant to the present Initiative.

<u>Occupational/Environmental Exposure Studies.</u> Across DoD laboratories, and within MRMC in particular, a large number of laboratory-based studies have focused on characterizing the effects of operational and environmental exposures on Warfighter cognitive performance and readiness. Among the diverse array of possible operational and environmental exposures, sleep loss/restriction (Wesensten et al. 2002, Lieberman et al. 2008, Estrada et al. 2012, Heaton et al. 2014, Kamimori et al. 2015, Smith et al. 2017) and extreme environmental conditions including heat (Fine 1987, Cheuvront et al. 2004), cold (Mahoney et al. 2007, O'Brien et al. 2007, Adam et al. 2008, Lieberman et al. 2009), and altitude (Shukitt-Hale et al. 1991) have received the most attention. In addition to these operational and environmental exposure scenarios, the effects of nutritional/hydration status (Cheuvront et al. 2004, Adam et al. 2008, Montain and Tharion 2010, Lindseth et al. 2013, Lieberman et al. 2017), spatial disorientation (Webb et al. 2012), degraded visual environments (Capó-Aponte et al. 2009), and physical exertion (Mahoney et al. 2007, May 2009, Montain and Tharion 2010) on Warfighter cognitive readiness and performance have also been examined. Many of these laboratory-based studies involved exposures to more than one stressor in an effort to more closely model exposure scenarios encountered under actual operational conditions (Lieberman et al. 2005). Other studies have sought to characterize the effects of operationally-relevant exposures on performance of specific military-relevant tasks, such as military marksmanship (Johnson and Merullo 1996, Johnson and Merullo 2000, Kerick et al. 2007). Many studies use multiple measures of cognitive status and performance and in a few, these measures were systematically compared to determine their relative sensitivity to military-relevant stressors. For example, Balkin and colleagues (Balkin et al. 2004) compared commercial drivers' performance on several measures of cognitive function, mood, oculomotor performance, and sleep latency under restricted sleep conditions to determine the relative sensitivity of each measure to the effects of insufficient sleep. With the emergence of advanced virtual/synthetic training environments, validation of measures for predicting military performance in laboratory settings will have increased ecological validity as technology develops.

<u>Physiology-based Studies</u>. In addition to the more traditional measures of cognitive performance that assess domains of cognitive function such as memory, attention, visual spatial and verbal capabilities, physiology-based measures provide a measure of cognitive and

affective state. In the 1990s, a panel was convened by the Working Group for Aerospace Research & Development (AGARD) of the North Atlantic Treaty Organization (NATO) to determine if physiological measurements could predict cognitive function among crew during flight operations (Caldwell et al. 1994). The panel only considered performance issues related to the NATO air forces; however, the approach of using physiological measurements (EEG, heart rate variability, etc.) to evaluate cognitive state has received increasingly more attention, particularly with advances in sensor technologies (Wilson 2002). Relevant to the AGARD report, the Defense Advanced Research Projects Agency (DARPA) initiated the Augmented Cognition program in 2001 to develop cognitive monitoring and performance improvement strategies for military personnel engaged in mentally demanding tasks (Morrsion et al. 2006). Phase I of the program resulted in a Technical Integration Experiment (TIE) report that described a set of "cognitive gauges" to assess changes in attention and executive function during a military-relevant air traffic control task (St. John et al. 2003). In Phase II of this work (Morrsion et al. 2006), the cognitive gauge approach was expanded to other branches of the Armed Forces and included mitigation strategies to optimize the users' cognitive resources during high demand tasks. For example, Honeywell and its partner universities were selected to use EEG (and other techniques) to measure attentional resources in participants engaged in Army-relevant tasks such as simulated navigation and communication. Although reportedly successful, limited details are available regarding the specific methods used and task validity. Also, these efforts involved small participant samples composed of civilian university students, raising questions regarding the generalizability of the findings to a military population.

Simulation and Field-based Studies

Numerous investigators have endeavored to measure cognitive performance using simulated task environments or actual military field environments. Simulations such as those involving flight (Russo et al. 2005) and marksmanship (Lieberman et al. 2002, Smith et al. 2017) simulate real military tasks while measuring a variety of cognitive functions including memory, reaction time, and decision-making. Furthermore, numerous operational and environmental stressors can be independently modified to examine consequences on performance. For example, during an overnight mission on a flight simulator, pilots made significantly more azimuth deviations following extended periods of wakefulness [a measure that significantly correlated with performance on the psychomotor vigilance task (PVT, Russo et al. 2005)].

In addition to simulators, cognitive assessments in actual operational settings have been conducted using participants from the Special Forces and Army of Allied nations (Lieberman et al. 2002, Lieberman et al. 2005, Lieberman et al. 2005, Kamimori et al. 2015), Navy (Lieberman et al. 2002), and Marines (McClung et al. 2011) or before and after deployment among Army Active Duty and National Guard participants respectively (Operation Iraqi Freedom; Vasterling et al. 2006, Proctor et al. 2009). Reaction times, as measured by the PVT or similar visual vigilance tests, have been shown to slow after sustained operations that include extended periods of wakefulness among Army Special Forces (Kamimori et al. 2015) and Navy SEAL candidates (Lieberman et al. 2002). Affected performance on other traditional cognitive measures includes matching-to-sample, repeated acquisition, four-choice reaction, and logical reasoning tests. Among the prospective study of OIF deployed Soldiers, reaction time on the

Simple Reaction Time test was significantly faster (Vasterling et al. 2006), while reduced proficiency on verbal learning and visual spatial task performances were observed.

Although some of these research efforts required participants to halt their mission-related activities to complete a cognitive assessment, others have attempted to unobtrusively measure cognitive performance. A group of Army Rangers, for example, reacted to an auditory cue from a wristwatch-style device before and after a strenuous course of running and ruck marching activities (Lieberman et al. 2002). Results showed that reaction times changed throughout periods of rest and exertion and were sensitive to nutrition supplementation. Other research has explored the relationship between military occupational chemical exposures (Proctor et al. 2011, Heaton et al. 2017) and environmental exposures (Banderet and Shukitt-Hale 2002) on cognitive function in field settings. Although these studies succeed in using valid approaches to measure cognitive performance as a result of strenuous military operations, the relationship between cognitive test outcomes and performance of actual military job tasks is unclear. In other words, it is not known how decrements in cognitive processing affect the Warfighters' ability to optimally perform their assigned tasks. An exception to this finding was a study that evaluated simulated marksmanship performance in Navy SEALs engaged in training exercises. In this study, marksmanship performance significantly degraded after exhaustive training (Lieberman et al. 2002).

Embedded Measures

Because they require no extra effort and/or 'time off task' by the operator, "embedded" measures derived from data already being captured (or easily captured) as the Warfighter executes his/her mission-essential tasks are desirable. Possibilities include (but are not limited to) analysis of voice data (e.g., verbal fluency metrics derived from voice data; see Sugarman and Axelrod 2015), on-board systems to monitor lane deviation and other aspects of driving performance as indicators of fatigue and/or impaired attention (e.g., Morris et al. 2015), measured marksmanship accuracies and response times during live fire exercises, and any military task performed on a computer (such as piloting unmanned aerial vehicles or UAVs). The advantages of measuring military-relevant performance directly - rather than measuring cognitive performance separately and then transducing the results into a prediction of military performance efficacy – are self-evident. But, at this point in time, there are only limited measures of this type that have been validated for use. As digital technology becomes a larger part of all Warfighters' battlefield activities other opportunities for direct measurement of cognitive function should emerge.

Self-Report Assessment Techniques

Many military investigators have successfully used validated self-report questionnaires to assess cognitive states, such as workload, fatigue and anxiety in both the laboratory and field environments (Lieberman et al. 2002, Lieberman et al. 2005) and many military test batteries include such measures**.** Unfortunately, these self-report questionnaires are often considered to be less 'valid' than tests of cognitive performance (perhaps because responses on such instruments may reflect the responder's subjective biases and desires – e.g., to "remain in the fight" – to a greater extent than objective measures that are less susceptible to such influences). However, in practice, self-report measures have often been found to be more sensitive to military-relevant stressors (e.g., dehydration and calorie deprivation) than tests of cognitive performance (Lieberman et al. 2017). In addition, it has repeatedly been established that responses to self-report questionnaires are correlated with real world performance outcomes (Glenville et al. 1978, Nicholson and Stone 1986, Bolmont et al. 2000, Lieberman 2006). It should also be noted that self-report, survey-based tasks are often more practical for deployment than tests of cognitive performance or physiological measures such as EEG. Such tests should always be included in test batteries since they provide information that cannot be derived from tests of performance (Lieberman 2005). Existing self-report questionnaires should be validated for their ability to predict real world military performance and correlate with new measures developed.

Summary

One key element of Phase I of this Initiative has been to review research aimed at advancing development and validation of cognitive assessment tools and approaches for use in evaluating Warfighter cognitive performance. Dozens of studies have described changes in cognitive performance that occur in parallel with military occupational and environmental exposures and experiences, but only a small subset have attempted to integrate cognitive performance with real-world military tasks (e.g., marksmanship, aircraft operation, and driving). The conclusion from Phase I of this Initiative is that **the goal of accurately and efficiently determining Warfighter cognitive status and predicting performance under military training and operational conditions has yet to be achieved.** Significant limitations on the desired goal of moving cognitive assessment capabilities and assets from the laboratory to the field exist. These factors include:

- Complexity of cognitive contributions to Warfighter task performance,
- Lack of cognitive assessment tools and approaches with sufficient sensitivity to detect subtle shifts in cognitive status, and
- Challenges inherent in evaluating and predicting cognitive performance in real-time and under military training and operational conditions

These challenges have likely contributed to the observation that many of the task batteries developed as part of working groups or other efforts have not been widely implemented or utilized outside the laboratories in which they were developed. Moreover, such challenges, coupled with shifting funding priorities and other factors also may have hampered efforts of previous groups to create a sustainable, coordinated Warfighter cognitive assessment program within DoD to address the critical and ongoing needs of providing more complete Warfighter performance assessment – one including both brain and body – to achieve the goals of sustaining and optimizing Warfighter cognitive health (readiness) and performance.

Chapter 3. Identified Gaps

As described in Chapter 1, the primary aim of Phase I of this Initiative was to evaluate the current state of the science for assessment of Warfighter cognitive performance within military operational and training environments. This assessment was based on responses provided by investigators at USARIEM, WRAIR, and USAARL to a semi-structured survey (**Appendix A**), information gathered through an extensive review of the research literature (**Appendix B**), and communications with stakeholders across the DoD. The results of Phase I efforts were discussed in Chapter 2. During the Phase I effort, analysis of the information obtained by the Working Group led to the identification of four key gaps in current cognitive assessment capabilities within MOMRP (and beyond). The first two gaps focus on the limitations in the available cognitive testing research toolkit and the last two gaps focus on the limits within the current research infrastructure. These gaps are detailed below.

Gap #1.

Despite widespread availability of validated cognitive assessment tools and approaches, there is a significant lack of empirical research evidence linking performance on these assessments to military-relevant performance standards.

A review of the literature produced a large number of peer-reviewed manuscripts and technical reports pertaining to assessment of Warfighter cognitive performance in both real-world (training and operational) and simulated real-world environments. Analysis of this literature revealed a wide range of cognitive assessment tools and approaches. However, there were few measures with documented validation for use in predicting complex Warfighter performance outcomes in real-world military settings. This is largely because, at present, the scientific community lacks sufficient understanding of the cognitively-demanding elements of military job tasks and their successful (or unsuccessful) performance. In addition, efforts systematically mapping or linking of specific cognitive proficiencies to real-world military task performance (e.g., job task analysis with a focus on cognitive aspects of performance) have rarely been conducted.

This observation was supported by researchers within MOMRP laboratories and across the DoD who commented they had adequate access to a variety of cognitive assessment tools for use in laboratory and simulated field studies but that validated measures providing accurate prediction of Warfighter performance under real world conditions were lacking. It also was noted that each study included a distinct set of cognitive tests that were often different across studies examining similar performance outcomes. Failure to utilize common tests or data elements across studies impairs the ability to compare findings across studies and to draw meaningful conclusions regarding the effects of cognitive performance degradations on military task performance. At this time, the Working Group cannot recommend a core battery of tests to provide common data elements for comparison purposes across studies because a sufficient evidence base providing the necessary objective validated data to create such a battery does not exist.

Gap #2.
Available cognitive assessment tools and approaches often lack adequate sensitivity and specificity to predict or detect changes in military task performance before severe (i.e., operationally meaningful) degradation occurs.

Our review of the literature and communications with researchers within MOMRP and across the DoD highlighted two issues related to the sensitivity and specificity of available measures. The first issue suggests that while many assessment tools have been validated to measure discrete aspects of cognitive performance for clinical evaluation purposes, such measures do not necessarily have sufficient sensitivity to detect meaningful changes in cognitive function in healthy, fit individuals, such as Warfighters, regardless of setting (laboratory or real-world environments). Moreover, the extent to which currently-available cognitive assessment tools and approaches reflect, capture, or measure the complex cognitive processes required to adequately (or optimally) perform within real world military training or operational environments is currently unknown.

The second issue is that while some measures may be sensitive to changes in aspects of cognitive performance under a variety of military relevant exposure conditions, such as exposure to environmental extremes, sleep loss, or stressful training scenarios, such measures are not necessarily able to differentiate the underlying source or causal factor for the change in performance (i.e., specificity). For example, the psychomotor vigilance test (PVT) is significantly sensitive to sleep loss (and is currently considered the gold standard of behavioral measures of sleepiness) but it is also sensitive to drugs/alcohol, environmental distractions, motivation, etc. – thus limiting its utility for informing decisions regarding appropriate interventions. In addition, there is insufficient evidence supporting the predicative validity of currently available cognitive measures for determining how well a Warfighter will perform his or her military job tasks under diverse training or operational conditions, including the high stress environment of combat.

Gap #3.
A historical lack of coordinated communications among MRMC researchers, as well as between MRMC researchers and non-MRMC collaborators (e.g., universities, industry and small businesses, other DoD laboratories), has hampered progress toward advancing effective, validated cognitive assessment capability within military training and operational environments, occasionally resulting in uncoordinated efforts and failure to leverage limited financial and human resources.

Researchers within MOMRP and across the DoD who responded to requests for input as part of Phase I of this Initiative frequently noted they were often surprised to discover similar and often overlapping lines of work at laboratories outside their own. They expressed concern regarding the uncoordinated nature of such efforts, an occurrence which, it was noted, could be avoided with more communication and coordination across branches of service and organizations both within and outside of the DoD. Researchers also noted that this lack of communication limited opportunities to collaborate, and thereby more efficiently and effectively utilize limited financial and human resources (such as access to research volunteers).

Gap #4.

A historical lack of coordinated communication between the DoD research and training and operational communities (stakeholders) has limited progress in providing effective, targeted solutions to leaders and Warfighters to sustain and enhance cognitive health and performance within military training and operational environments.

Historically, there has been insufficient understanding of how specific Warfighter cognitive proficiencies contribute to performance outcomes on military relevant tasks. Before solutions can be recommended to sustain or enhance Warfighter cognitive health and performance, there must first be an understanding of what areas of cognitive performance contribute to effective military job or training performance. Researchers within MOMRP and across the DoD surveyed for this Initiative noted that although some progress is underway, in many cases, we, as a research community, may not have sufficient knowledge of the cognitive proficiencies that are required to successfully perform specific military relevant job or tasks. Similarly, cognitive proficiencies that, when degraded, contribute to impaired performance are also unclear. To gain this knowledge, SME's in the research community need to communicate and work directly with schoolhouses, instructors/coaches, operational leaders and Warfighters to identify appropriate performance elements or targets for cognitive assessment.

Chapter 4: Recommendations and Research Roadmap to Close Cognitive Assessment Gaps

Based on review and analysis of information gathered from the research literature and from communications with scientists within MOMRP and across the DoD, the CPRAI Working Group identified four key gaps in cognitive assessment capabilities for evaluating and predicting Warfighter performance in military training and operational environments. In this chapter, we describe the Phase II efforts of the Initiative, beginning with a description of specific recommendations to close each of these four gaps. Then, these recommendations have been consolidated into a proposed framework or Research Roadmap for providing validated cognitive assessment capability to evaluate and predict Warfighter performance within diverse military settings.

Recommendations to Close Gap #1

Gap #1 states that empirical research evidence linking performance on cognitive measures to military-relevant performance standards is lacking. Specific recommendations to close this gap include:

1) Engage training and operational leaders and instructors through focus groups, structured interviews, qualitative research projects, and other means to a) determine the range of Warrior skills that military members are responsible for learning and mastering, including key Warfighter cognitive attributes and skills necessary for successful performance, and b) identify what constitutes "successful performance" under complex exposure scenarios.

2) Engage operational leaders, SMEs, Warfighters to identify key Warfighter performance elements or outcomes. For example:
   a) Which military job activities or tasks are the most, and least, demanding from a cognitive, visual, auditory, and physical perspective?
   b) Which military job activities or tasks appear to be most affected by stressors, such as lack of sleep, need to multitask, etc.?
   c) What cognitive factors most contribute to accidents or on-the-job mistakes? Look to the established literature pertaining to accidents and accident investigations and conduct an in-depth review of the literature to guide future research objectives.
   d) What types of deliverables are desirable from the training and operational perspective?

3) Guided by input from leaders and stakeholders (Recommendations #1 and #2), develop and implement research to evaluate the efficacy of the identified performance elements/outcomes and to establish standards and thresholds (i.e., metrics) relevant to performance on military job tasks within complex operational settings.

4) Promote development and use of simulated field environments or scenarios to model complex, multi-exposure, operationally-relevant conditions in which to test and validate cognitive assessment approaches and tools and prediction models of cognitive determinants of Warfighter performance.

Recommendations to Close Gap #2

Gap #2 notes that currently available cognitive assessment tools and approaches often lack adequate sensitivity and specificity to predict or detect changes in military task performance before meaningful degradation occurs.

1) Identify standards/metrics by which cognitive assessment technologies and approaches are evaluated and how validity is determined within military settings.

2) Develop and validate assessment tools and approaches tailored to metrics identified in collaboration with military SMEs as critical for optimal performance and readiness under complex military exposure scenarios.

3) Develop and implement research objectives to support validation of predictive models of performance degradation that leverage a range of data inputs, including physiology-based measures and biomarkers (e.g., voice/facial expression features, eye movement/gaze, heart rate, heart rate variability, skin temperature, skin conductance, etc.) and self-report measures of performance, effort and mood, for evaluation of cognitive performance and readiness.

4) Establish benchmark or performance indicator metrics that sensitively and accurately predict initial stages of degraded cognitive performance before military job task performance or mission success is impacted.

5) Identify a common core of validated cognitive assessment tools (data elements) as part of a standardized, research approach to facilitate cross-study comparisons of research findings.

Recommendations to Close Gap #3

Gap #3 identified the lack of communication and coordination among MRMC and non-MRMC scientists, as well as between DoD and non-DoD researchers as an impediment to providing effective, validated cognitive assessment capability within military training and operational environments, occasionally resulting in uncoordinated efforts which could be improved by regular communication with other investigators addressing similar issues, and failure to leverage limited financial and human resources. Specific recommendations to close Gap #3 are provided below.

1) Establish a framework for and implement regular opportunities for scientists (MRMC and non-MRMC), training and operational leaders and other stakeholders (e.g., community of interest or COI) to meet and discuss needs and priorities with respect to Warfighter cognitive health, performance and medical aspects of cognitive readiness.

2) Establish a MOMRP program of research to coordinate and implement scientific effort and to support ongoing communication across the scientific community with respect to cognitive health, performance and the medical aspects of cognitive readiness.

3) Establish and support a searchable, indexed directory of Principal Investigators engaged in cognitive research within the DoD, to include information pertaining to active research projects and source of funding.

Recommendations to Close Gap #4

Gap #4 cited the lack of coordinated communication between the DoD research and training and operational communities as contributing to limited progress in providing effective, targeted solutions to leaders and Warfighters to sustain and enhance cognitive health and performance within military training and operational environments. Specific recommendations to close this gap are provided below.

1) Establish a framework for, and implement regular opportunities for, scientists and stakeholders to meet and discuss needs and priorities with respect to Warfighter cognitive performance and readiness.
2) Identify and support opportunities for scientists to gain first-hand experience with Warfighters at all levels within operational settings. This might include targeted "greening" opportunities, dedicated field exercise observation days, or other opportunities to interact with the training and operational community.
3) Establish a MOMRP Program of Research to coordinate and implement scientific effort and support ongoing communication and collaboration between the scientific community and stakeholders with respect to the assessment of cognitive health, performance and the medical aspects of cognitive readiness.

Research Roadmap

Through the course of this Initiative, the Working Group determined that despite the widespread availability of tools and approaches for measuring numerous aspects of cognitive functioning, the relationship between a Warfighter's performance on a given cognitive assessment and his/her military job or training performance is unknown, so to propose a common battery of cognitive tests for use at this point is not possible. In addition, the specific cognitive resources that are required for performance of a given military task, as well as the cognitive proficiencies that contribute to success or failure on a specific job or task are often unclear.

To address these gaps, the Working Group has proposed a Research Roadmap (or Program of Research) for identifying and validating a set of cognitive tools to evaluate and predict Warfighter performance in diverse military settings. It is intended that this approach provide a standardized strategy for validating cognitive assessment measures that may be included, if appropriate, in a ***common battery of tests*** for assessment of Warfighter performance. This core task battery will provide common data elements that also will facilitate cross-study comparisons.

The Research Roadmap proposed by the Working Group aims to initially identify cognitive proficiencies required for successful performance of 2-3 common military job tasks. Cognitive assessment tools will be selected and validated to reliably and validly predict performance on these tasks under real world or simulated real world exposure conditions. This approach is intended to be replicable across other military job tasks and settings to enable systematic evaluations of additional military jobs or activities, as well as other existing cognitive assessment tools or emerging technologies over time. The approach recommended by the Working Group draws from established standards of practice across diverse scientific fields, including epidemiological field research, behavioral measurement theory and test development, as well as standard clinical cognitive assessment practices.

Specific objectives across the proposed Program of Research are detailed below.

<u>Near Term Objectives (Years 1-2)</u>

Near Term Objectives for the proposed programmatic solution are focused on providing initial proof of concept of a standardized approach for characterizing the cognitive elements of performance associated with a discrete set of common military job tasks, identifying appropriate cognitive tools or approaches for evaluating identified cognitive domain targets, and establishing and validating the linkages between performance on these cognitive tests and performance of military job tasks.

Objective 1: Establish a board of advisors, including SMEs from all branches of service and representatives from the operational community, to provide guidance for cognitive assessment initiatives across the DoD. This Objective addresses Gaps #3 and #4.

- Board will coordinate opportunities for SMEs across the DoD to gather at relevant professional meetings, or other venues as appropriate, to assist in the ongoing development and coordination of cognitive performance assessment capabilities.
- It is the recommendation of the Working Group that this Board meet at least annually, and communicate with Research Program leadership, to plan and coordinate efforts across branches of service.

Objective 2: Select 1 to 3 military jobs that afford researchers the ability to closely observe Warfighter activities in relatively controlled settings to reduce the potential influence of confounding exposure factors on performance. This Objective addresses Gaps #2 and #4.

- Engage military leaders and Warfighters through focus groups, structured interviews, qualitative research projects, and other means to define key dismounted Warfighter tasks (common and MOS specific) to provide recommendations for appropriate activities that are amendable to controlled research investigations (e.g., marksmanship decision-making or certain Unmanned Aerial Vehicle (UAV) operations).

- Work with SMEs, military leaders and Warfighters to define "successful performance" targets for these jobs to facilitate identification of appropriate standards and thresholds (i.e., metrics) for performance.
- In addition, work with SMEs, military leaders and Warfighters (e.g., through focus groups) to identify cognitive proficiencies that, when degraded, contribute to mistakes on job tasks or to mission failures will be ascertained; conduct literature review to identify key areas of vulnerability for accidents.

Objective 3: Identify the key cognitive attributes and skills necessary for successful performance of the targeted jobs or job tasks. This Objective addresses Gap #1.

- Work with SMEs, military leaders and Warfighters to identify cognitive proficiencies that aid job performance and those that hinder job performance.

Objective 4: Propose a core battery of cognitive tasks, based on historical and recently completed cognitive assessment of Warfighter performance on specified tasks and/or under specific critical military stressors. This Objective addresses Gaps #1 and #2.

- Continue the conduct of more extensive, targeted literature reviews to identify additional tests/technologies by specified cognitive functional domain (Appendix B provides a detailed list of cognitive assessment tools that have been utilized in previous studies in which the cognitive aspects of Warfighter performance were evaluated.)

Mid Term Objectives (Years 3-4)

Mid Term Objectives for the proposed programmatic solution will be focused on implementing targeted research to establish the linkages between cognitive test performance and performance on selected military job tasks under a variety of exposure conditions. This research should leverage cognitive performance proficiencies and job task performance standards identified as part of the Near Term Objectives, as well as cognitive assessment tools, either established measures or emerging technologies or approaches, identified for measurement of the identified cognitive performance targets.

Objective 1: Conduct controlled studies to evaluate the validity and reliability of selected cognitive tests for assessment of Warfighter performance on selected military work task(s) under 2-3 military-relevant exposure conditions. This Objective addresses Gaps #1 and #2.

- The use of simulated field environments or scenarios is encouraged in order provide relevant complex, multi-exposure, relevant conditions within relatively controlled settings.
- Whenever feasible, multiple performance measures, physiology-based measures and biomarkers (e.g., voice/facial expression features, eye movement/gaze, heart rate, heart rate variability, skin temperature, skin conductance, etc.), and self-report measures of performance, effort and mood, should be incorporated into the

research design. This will provide a wider range of performance outcome targets to support predictive modeling objectives.

Objective 2: Evaluate the continuum of or gradations in performance to establish standards and thresholds (i.e., metrics) relevant to performance on military job tasks. This Objective addresses Gaps #1 and #2.

- Engage military leaders and Warfighters to assist in the delineation/definition of meaningful change on targeted assessments.

Objective 3: Propose a core battery of cognitive tasks, based on historical and Program research efforts, which provides a 65% solution of valid cognitive assessment of Warfighter performance of specified tasks or in the face of critical military stressors. This Objective addresses Gaps #1 and #2.

Far Term Objectives (Year 5)

Far Term Objectives for this effort will be to utilize performance standards identified in Years 1-4 to inform sensitivity analyses to determine early markers of performance degradation for individual cognitive tests.

Objective 1: Conduct sensitivity analyses to determine early markers of performance degradation for individual cognitive tests. This Objective addresses Gap #2.

Objective 2: Develop predictive models with traditional and machine learning techniques using cognitive test performance to predict military job task performance. This Objective addresses Gap #1.

Objective 3: Develop reliable change indices based on performance outcomes obtained across Years 1-4 of this effort using appropriate statistical modeling procedures. This Objective addresses Gaps #1 and #2.

Objective 4: Apply 'mathematical modeling' procedures to delineate the association between indices of cognitive function (most likely derived from a combination of subjective and objective measures) and specific military job task performance outcomes. Mathematical models can greatly enhance the ability to detect negative trends in performance before critical thresholds are crossed (e.g., potentially resulting in catastrophic errors) and apply optimally-timed and -dosed countermeasures or interventions to sustain operational effectiveness. This Objective addresses Gap #1.

Objective 5: Propose a core battery of cognitive tasks, based on historical and Program research efforts, which provides an 80% solution of valid cognitive assessment of Warfighter performance of specified tasks or in the face of critical military stressors. This Objective addresses Gaps #1 and #2.

Conclusion

Despite a myriad of available cognitive assessment tools and approaches, the goal of determining Warfighter cognitive state and predicting performance under training and operational conditions has not been achieved. At present, the primary factors limiting progress toward achieving efficient and effective assessment of Warfighter performance appear to be a i) lack of understanding of the cognitively-demanding elements of military job requirements and related tasks and standards, ii) insufficient empirical evidence linking performance on cognitive assessments to military-relevant performance standards, iii) a dearth of cognitive tools and metrics with adequate sensitivity, specificity and ecological validity to predict or detect meaningful changes in military task performance, and iv) insufficient/ineffective coordination of communications regarding cognitive performance assessment among MOMRP researchers, non-MOMRP collaborators, military training and operational leaders and stakeholders.

The intent of the proposed Research Roadmap (Program of Research) outlined in this Final Report is to present a standardized approach to achieve effective, accurate, valid assessment of the cognitive aspects of Warfighter performance for select military job tasks. While the initial focus of this Roadmap is to identify a set of validated cognitive measures that can predict Warfighter performance on a select subset of military job tasks, it is intended that this approach, once established, be applied to additional military job tasks, including those tasks that are shared across all branches of service, as well as those that are unique to specific military occupational specialties to facilitate further closure of the identified gaps. Finally, increased communication *and coordination* across MRMC, DoD, and non-DoD laboratories and programs will contribute toward the shared objectives of providing innovative, effective, and relevant solutions for early detection of degraded Warfighter cognitive performance and relevant solutions for optimizing and enhancing Warfighter cognitive performance within military training and operational settings.

Disclaimer

The opinions or assertions contained herein are the private views of the author(s) and are not to be construed as official or as reflecting the views of the Army

Acronyms

ACRA	Army Cognitive Readiness Assessment
AGARD	Advisory Group for Aerospace Research & Development (AGARD)
ANAM	Automated Neuropsychological Assessment Metrics
BCT	Basic Combat Training
COI	Community of Interest
CPJDRP	Cognitive Performance, Judgment, and Decision-Making Research Program
CTS	Criterion Task Set
DANA	Defense Automated Neurobehavioral Assessment
DARPA	Defense Advanced Research Projects Agency (DARPA)
DoD	Department of Defense
EEG	Electroencephalogram
fNIR	Functional Near Infrared Spectroscopy
HPO	Human Performance Optimization
JWGD3 MILPERF	Joint Working Group on Drug Dependent Degradation in Military Performance
MEDCOM	United States Army medical command
NMCFT	Neurophysiological Measure and Cognition Focus Team
MOS	Military Occupational Specialty
MRMC	Medical Research and Materiel Command
MOMRP	Military Operational Medicine Research Program
MOPP	Mission-Oriented Protective Postures
MRI	Magnetic Resonance Imaging
NATO	North Atlantic Treaty Organization
NMCFT	Neurophysiological Measure and Cognition Focus Team
PAD	Program Area Director
PET	Positron Emission Tomography
PETER	Performance Evaluation Tests for Environmental Research
POC	Point of Contact
PVT	Psychomotor Vigilance Test

SME	Subject Matter Expert
TIE	Technical Integration Experiment
UAVs	Unmanned Aerial Vehicles
USAARL	United States Army Aeromedical Research Laboratory
USARIEM	United States Army Research Institute of Environmental Medicine
UTC-PAB	Unified Tri-Service Cognitive Performance Assessment Battery
WRAIR PAB	Walter Reed Performance Assessment Battery
WRAIR	Walter Reed Army Institute of Research

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Appendix A. Phase I Semi-Structured Investigator Survey

Electronic Message to Researchers, Initiated Spring and Summer 2016

USARIEM (Drs. Proctor and Heaton) has been tasked by MOMRP to coordinate an effort to i) summarize current state-of-knowledge regarding assessment of cognitive function/performance in military-relevant environments (field and laboratory) and ii) make recommendations regarding validated cognitive-behavioral assessments/approaches for use in determining/predicting functional status and readiness in humans.

The types of assessments we are summarizing include the following:

- Cognitive measures or tests (e.g., measures of memory, attention, judgment and decision making)
- Brain imaging/neurophysiological measures (e.g., MRI, spectroscopy/neurochemical, EEG, fNIR)
- Neuromotor function (e.g., reaction times, finger/hand dexterity, eye tracking, other modalities)
- Physiological measures that may be used to enhance assessment or prediction of cognitive state, such as heart rate, respiratory rate, skin conductance/temperature, stress hormone levels, etc.

The purpose of this message is that, in addition to conducting an extensive literature search, we want to reach out to investigators who are actually using cognitive-behavioral assessments in their research.

If you have or are currently using cognitive-behavioral assessments in your studies, we would like to get your input on a few questions. These questions and a table summarizing the information we are hoping to obtain from you are detailed below. We would very much appreciate any information you can provide, in whatever format is easiest for you. If you would prefer to give us this information in person, just let us know and we will schedule a time to meet with you.

Please let us know if you have any questions. Again, we very much appreciate any information you can provide. We would like to receive your response (negative responses if appropriate) by COB DD/MM/YYYY.

V/R,
Kristin and Susan

Questions about your research:

In evaluating/predicting “brain health and performance” in your research, which instruments have you found to be most useful/valid?

In what settings were these instruments used (laboratory study, field study)?

What do you feel are significant gaps/needs in the area of Warfighter cognitive performance assessment?

What tools/resources would be most helpful to you in your research involving cognitive performance assessment?

TABULAR SUMMARY* to describe your research in this area:

Type of Study (field/laboratory/ database)	Study Objective(s)	Instruments Used	Was this instrument/test/ assessment developed for use in this study (not previously published)	Results of Assessment

Appendix B. Cognitive Assessment Tools

This table provides a sampling of cognitive assessment measures used to evaluate Warfighter cognitive function. Search criteria included those studies that evaluated military-relevant exposure and stress conditions (e.g., environmental, occupational, combat-related stress), and involved healthy, non-injured Warfighters (or civilians, as relevant) with particular emphasis on studies conducted in field settings. This table is not intended to be exhaustive of the measures used to evaluate Warfighter cognitive function, rather it is intended to provide examples of the types of measures that have been used in previous research and the settings in which they have been used.

Domain/Test	Test Description	Type of Administration	Setting/Exposure or Condition/Reference
Executive Function			
Biber Cognitive Estimation Test	Estimation of unknown values	P, E	**Lab:** Sleep Loss, Stimulants (Killgore et al. 2008)* **Lab:** Sleep Loss, Stimulants (Wesensten et al. 2005)*
Go-No-Go	Test of response inhibition and selective attention	C, S	**Lab:** Heat, cold, humid (environmental chamber) (Haran et al. 2016) Involved DANA Brief[e]
Stroop Color and Word Test	Test of selective attention, cognitive flexibility, and response inhibition	P, E	**Lab:** Sleep Loss, Stimulants (Wesensten et al. 2005)
Tower Test	Tests strategy development and execution, spatial planning	C, S	**Lab:** Simulated Low - Moderate Altitude (chamber) (Pilmanis et al. 2016) [d]
Wisconsin Card Sort Task	Evaluates concept formation, abstract reasoning and ability to shift set	C, S	**Lab:** Sleep Loss, Stimulants (Wesensten et al. 2005)
Attention			
Attention Network Test	Assesses primary attention networks of alerting, orienting and executive control	C, S	**Lab:** Sleep Loss (Heaton et al. 2014)* **Lab:** Caffeine effects on performance (Brunyé et al. 2010)*
Continuous Performance Task (CPT)	Primarily a test of attention, although working memory is also involved	C, S	**Lab:** Simulated Low - Moderate Altitude (chamber) (Pilmanis et al. 2016)* [d] **Field:** Military occupational exposure to jet fuel (JP-8) (Proctor et al. 2011, Heaton et al. 2017) [d]
Digit Span Forward (Wechsler Adult Intelligence Scale III)	Primarily a test of attention, although working memory is also involved	P, E	**Field:** Military occupational exposure to jet fuel (JP-8) (Proctor et al. 2011, Heaton et al. 2017)
Divided Attention	Tests ability to process information from different sources concurrently.	C, S	**Lab:** Environmental Chamber, body armor, heat (van der Henst BSc 2011) [c]

Field Vigilance Test	Record the nature of activity occurring in and around a building.	S	**Field:** Special Forces; caffeine; sleep loss (Kamimori et al. 2015)*
Filtering	Test of selective attention	C, S	**Lab:** Environmental Chamber, body armor, heat (van der Henst BSc 2011) [c]
Mobile Vigilance Monitor	Measure of attention and speed of responding	C, S	**Lab/Field:** Nutritional Intervention (Lieberman et al. 2002)* **Field:** Special Forces; caffeine; Sleep Loss (Kamimori et al. 2015)* [c]
Mini Cog Vigilance	Measure of sustained attention	C, S	**Lab:** Environmental Chamber, body armour, heat (van der Henst BSc 2011)
Psychomotor Vigilance Test (PVT)	Measure of sustained attention	C, S	**Lab:** Caloric Deprivation (Lieberman et al. 2008) **Lab:** Sleep Loss (Killgore and McBride 2006)* **Lab:** Sleep Loss, Stimulants (Killgore et al. 2008)* **Lab/Field:** Modafinil, alertness, helicopter piloting (Field and simulator) (Estrada et al. 2012) [f] **Field:** Special Forces; caffeine; Sleep Loss (Kamimori et al. 2015)* **Field:** Driving simulator (Balkin et al. 2004) * **Field:** Marine Officer Training; nutritional supplementation to improve performance (McClung et al. 2011)*
Rapid Visual Information Processing	Test of visual sustained attention and working memory	C, S	**Lab/Field:** Modafinil, alertness, helicopter piloting (Field and simulator) (Estrada et al. 2012) *[f]
Scanning Visual Vigilance	Tests visual sustained attention	C, S	**Lab:** caffeine, diphenhydramine, or placebo (Tharion et al. 1993, Fine et al. 1994)* **Lab:** Cold, hydration (environmental chamber) (Adam et al. 2008) **Lab:** Caffeine or placebo; Sleep Loss (Doan et al. 2006)* **Lab:** Caloric Deprivation (Lieberman et al. 2008) **Lab:** Cold exposure (cold water immersion) (O'Brien et al. 2007) * **Field:** Ranger Training; Cold; Sleep Loss (Lieberman et al. 2009)* **Lab:** Cold, Tyrosine supplementation (Mahoney et al. 2007) **Field:** Caffeine or placebo (Lieberman et al. 2002)* **Field:** Military training; Heat; Sleep Loss (Lieberman et al. 2005)*
Working Memory			

Auditory Consonant Trigrams	Measures auditory working memory	P, E	**Field:** Military occupational exposure to jet fuel (JP-8) (Proctor et al. 2011, Heaton et al. 2017)
Auditory Switch Test	Measures auditory working memory and attention	C, S	**Lab:** Load carriage (backpack), balance (May 2009)*
Choice Reaction Time Test (single choice)	Tests working memory and speed of information processing	C, S	**Field:** Caffeine/Sleep Loss (Kamimori et al. 2000)* [b]
Choice Reaction Time Test (Two choice)	Tests working memory and speed of information processing	C, S	**Lab:** Simulated Low - Moderate Altitude (chamber) (Pilmanis et al. 2016) [d]
Code Substitution	Tests working memory and speed of information processing symbol/number pair	C, S/P, E	**Lab:** Simulated High Altitude (chamber) (Shukitt-Hale et al. 1991)* [a] **Lab:** Heat, cold, humid (environmental chamber) (Haran et al. 2016) Involved DANA Brief[e] **Field:** Ranger Training; Cold; Sleep Loss (Lieberman et al. 2009)*
Four-Choice Visual Reaction Time Test	Test of visual working memory and processing speed	C, S	**Lab:** Equipment testing (M40 Mask) during sleep (Lieberman et al. 1996)* **Lab:** Caloric Deprivation (Lieberman et al. 2008) **Lab:** Cold, Tyrosine supplementation (Mahoney et al. 2007)* **Lab:** Simulated High Altitude (chamber) (Shukitt-Hale et al. 1991)* **Field:** Caffeine/Navy SEAL Training (Lieberman et al. 2002)* **Field:** Ranger Training; Cold; Sleep Loss (Lieberman et al. 2009)* **Field:** Military training; Heat; Sleep Loss (Lieberman et al. 2005)*
Match-to-sample	Tests visual working memory and visual recognition memory	C, S	**Lab:** Caffeine or placebo; Sleep Loss (Doan et al. 2006)* **Lab:** Caloric Deprivation (Lieberman et al. 2008) **Lab:** Cold, Tyrosine supplementation (Mahoney et al. 2007)* **Lab:** Cold exposure (cold water immersion) (O'Brien et al. 2007) * **Lab:** Simulated Low - Moderate Altitude (chamber) (Pilmanis et al. 2016) [d] **Field:** Military training; Heat; Sleep Loss (Lieberman et al. 2005)* **Field:** Caffeine/Navy SEAL Training (Lieberman et al. 2002) **Field:** Military occupational exposure to jet fuel (JP-

			8) (Proctor et al. 2011, Heaton et al. 2017) [d]
Nova Scan Multitask	Measures continuous memory, working memory, spatial visualization (manikin)	C, S	**Lab:** caffeine or placebo; Sleep Loss (Doan et al. 2006)
Procedural Reaction Time	Test of working memory and processing efficiency involving a simple set of mapping rules	C, S	**Lab:** Heat, cold, humid (environmental chamber) (Haran et al. 2016) Involved DANA Brief[e]
Spatial Working Memory	Test of spatial working memory,	C, S	**Lab/Field:** Modafinil, alertness, helicopter piloting (Field and simulator) (Estrada et al. 2012) *[f]
Synthetic Workstation/Syn Task	Measures continuous working memory to four tasks (Sternberg Memory, 3 column addition, visual monitoring, auditory monitoring)	C, S	**Lab:** Equipment testing (M40 Mask) during sleep (Lieberman et al. 1996) **Lab/Field: P**hysical load (backpack)/road march (Knapik et al. 1997)) (auditory monitoring*)
Verbal Working Memory	Visual Working memory task	C, S	**Lab:** Environmental Chamber, body armor, heat (van der Henst BSc 2011) [c]
Sensation/Perception Functions			
Adaptive Tracking Task	Test of visual search and psychomotor coordination	C, S	**Lab:** caffeine or placebo; Sleep Loss (Doan et al. 2006)*
Choice Visual Perception Task	Assesses attention to visual stimuli within the lateral visual field.	C, E	**Lab:** Sleep Loss (Kendall et al. 2006)*
Hooper Visual Organization Test (HVOT)	Test of perceptual organization and visual spatial abilities	P, E	**Field:** Military occupational exposure to jet fuel (JP-8) (Proctor et al. 2011, Heaton et al. 2017)
Manikin Test	Measures spatial rotation ability, left-right orientation	C, S	**Lab:** Simulated Low - Moderate Altitude (chamber) (Pilmanis et al. 2016) * [d]
Pattern Recognition	Test of visual perceptual skills	P, E	**Lab:** Simulated High Altitude (chamber) (Shukitt-Hale et al. 1991) [a] **Field:** Ranger Training; Cold; Sleep Loss (Lieberman et al. 2009)*
Smell Identification Test	Test of olfactory acuity/discrimination	S	**Lab:** Sleep Loss (Killgore and McBride 2006)*
Stockings of Cambridge	Test of spatial planning abilities	C, S	**Lab/Field:** Modafinil, alertness, helicopter piloting (Field and simulator) (Estrada et al. 2012) *[f]
Spatial Processing Test	Test of visuospatial processing, spatial rotations	C, S	**Lab:** Simulated Low - Moderate Altitude (chamber) (Pilmanis et al. 2016) [d] **Lab:** Heat, cold, humid (environmental chamber) (Haran et al. 2016) Involved DANA Brief [e]
Vanderberg Mental Rotation Test	Evaluates spatial reasoning and mental rotation skills	C, S	**Lab:** General Aviation Trainer (flight simulator); dehydration (Lindseth et al. 2013)
Visual tracking	Test of visual motor movement, prediction/anticipation, adaptation	C, E	**Lab:** Sleep loss (Heaton et al. 2014*, Tong et al. 2014*) **Lab:** Oculomotor function and sleep loss (driving

			simulator) (Russo et al. 2003) *
Thinking Functions			
Basic Computations	Basic mathematical computations involving multiplications, additions, subtractions	C, P/S, E	**Lab:** Simulated High Altitude (chamber) (Shukitt-Hale et al. 1991)* [a] **Lab/Field:** Military Training Village; Dutch Infantry; Anxiety (Stress), Fatigue (Nibbeling et al. 2014)*
Controlled Oral Word Association Test	Test phonemic verbal fluency	S	**Lab:** Sleep Loss, Stimulants (Wesensten et al. 2005)
Decoding Messages	Decode pre-recorded, coded radio messages varying in length from five to eight words by using a simulated Army codebook and record the transcription	S	**Lab:** Chemical protective clothing; moderate heat exposure (Fine and Kobrick 1985)*
Friend-Foe Discrimination (Marksmanship)	Test of target identification and engagement decisions	S, E	**Lab:** Sleep Loss, Engagement Skills Trainer (Marksmanship) (Smith et al. 2017)* **Lab/Field:** Military Training Village; Dutch Infantry; Anxiety (Stress), Fatigue (Nibbeling et al. 2014)*
Grammatical Reasoning	Test of fluid reasoning	C, S	**Lab:** Caloric Deprivation (Lieberman et al. 2008) **Field:** Military training; Heat; Sleep Loss (Lieberman et al. 2005)* **Field:** Marine Officer Training; nutritional supplementation to improve performance (McClung et al. 2011)
Logical Reasoning	Test of nonverbal reasoning	C, S	**Lab:** Cold exposure (cold water immersion) (O'Brien et al. 2007) **Field:** Special Forces; caffeine; sleep loss ((Kamimori et al. 2015)*
Mathematical Processing	Test of nonverbal reasoning and computational skills	C, S	**Lab:** Simulated Low - Moderate Altitude (chamber) (Pilmanis et al. 2016) [d]
Map Grid Coordinates (using Army Code Wheel)	Receive and decode map grid coordinates using the standard Army Code Wheel	S	**Lab:** Chemical protective clothing; moderate heat exposure (Fine and Kobrick 1985)*
Plotting Targets on a Map	Plot targets on maps using an artillery plotting scale; determine range and deflection points using an artillery protractor	S	**Lab:** Chemical protective clothing; moderate heat exposure (Fine and Kobrick 1985)*
Serial Addition/Subtraction	Test of computational skills and working memory	C, S	**Lab:** Cold exposure (cold water immersion) (O'Brien et al. 2007) * **Lab:** Sleep Loss (Kendall et al. 2006)*
Site Calculation	Compute the asymmetrical trajectory of an artillery round using an artillery slide rule. The data necessary to compute the "Site" is tape-recorded prior to the study	S	**Lab:** Chemical protective clothing; moderate heat exposure (Fine and Kobrick 1985)*

Three-term reasoning	Test of verbal reasoning	C,S	**Lab: B**ody armor, heat (Environmental Chamber) (van der Henst BSc 2011) [c]
Learning & Memory			
Hopkins Verbal Learning Test	Measures verbal learning (list learning) and short term memory	P, E	**Field:** Military occupational exposure to jet fuel (JP-8) (Proctor et al. 2011, Heaton et al. 2017*)
Repeated Acquisition Test	Test of learning and working memory	C, S	**Lab:** Caloric Deprivation (Lieberman et al. 2008) **Lab:** Cold exposure (cold water immersion) (O'Brien et al. 2007) **Field:** Caffeine/Navy SEAL Training (Lieberman et al. 2002)* **Field:** Military training; Heat; Sleep Loss (Lieberman et al. 2005)*
Sternberg Memory Test	Test of working and short term memory	C, S	**Lab:** General Aviation Trainer (flight simulator); dehydration (Lindseth et al. 2013) **Lab/Field:** Nutrition Supplementation for performance (Walker et al. 2010)
Word Lists Memory	Test of verbal learning and short term memory	P, E	**Field:** Ranger Training; Cold; Sleep (Lieberman et al. 2009)*
Expressive Functions			
Vocal features	Includes analysis of prosody, pitch, pacing, coordination (etc.) of speech features	C, S/P, E	**Lab:** Cognitive overload (Quatieri et al. 2017)* **Lab:** Cognitive load (flight simulator) (Huttunen et al. 2011)* **Lab:** Sustained operations, fatigue (Huttunen et al. 2011)*
Facial Expression	Includes analysis of facial muscle activity/facial action units	C, S/E	**Lab:** Performance stress (Dinges et al. 2005)*
Motor Performance			
Grooved pegboard	Measure of finger dexterity, fine motor control	P, E	**Field:** Military occupational exposure to jet fuel (JP-8) (Proctor et al. 2011, Heaton et al. 2017)
Finger Tapping	Measure of motor speed	C, S	**Field:** Military occupational exposure to jet fuel (JP-8) (Proctor et al. 2011, Heaton et al. 2017) [d]
Marksmanship (general)	Test of neuromotor speed and coordination	S	**Lab:** Cold exposure (cold water immersion) (O'Brien et al. 2007) [c] **Lab:** Cold, hydration, exercise (environmental chamber) (Adam et al. 2008) (* cold) **Lab:** Low-moderate altitude exposure (altitude chamber) (Kryskow et al. 2013)* **Lab/Field:** Military Training Village; Dutch Infantry; Stress, Fatigue (Nibbeling et al. 2014)* **Lab/Field:** Modafinil, alertness, helicopter piloting

			(Field and simulator) (Estrada et al. 2012) [f] (used Engagement Skills Trainer, EST) **Field:** Caffeine/Navy SEAL Training (Lieberman et al. 2002) [c] **Field:** Special Forces; caffeine; sleep loss (Kamimori et al. 2015)
Minnesota Rate of Manipulation Test	Measure of gross hand dexterity	P, E	**Lab:** Cold exposure (environmental chamber) (O'Brien et al. 2011)
Purdue Pegboard	Measure of fine motor (hand and finger) dexterity	P, E	**Lab:** Cold exposure (environmental chamber) (O'Brien et al. 2011)*
Simple Reaction Time	Test of basic response speed and attention	C, S	**Lab:** Heat, cold, humid (environmental chamber) (Haran et al. 2016) Involved DANA Brief [e] **Field:** High altitude exposure (change from SRT1 at start of battery to SRT2 at completion of battery) (Roach et al. 2014)*[e] **Field:** Military occupational exposure to jet fuel (JP-8) (Proctor et al. 2011, Heaton et al. 2017)
Weapon Assembly/disassembly	Test of neuromotor speed and coordination; dexterity	S	**Lab:** Cold exposure (cold water immersion) (O'Brien et al. 2007) **Lab:** Low-moderate altitude exposure (altitude chamber) (Kryskow et al. 2013)

Individual tests taken from established assessment batteries: [a] Performance Evaluation Tests for Environmental Research (PETER); [b] Walter Reed Performance Assessment Battery; [c] Mini Cog Rapid Assessment Battery; [d] Automated Neuropsychological Assessment Metrics (ANAM) Version 4; [e] Defense Automated Neurobehavioral Assessment (DANA); [f] Cambridge Neuropsychological Test Automated Battery (CANTAB)

Type of administration: Computer (C), Paper & Pencil (P), Examiner (E), Self (S; following initial training/instruction).

*Denotes test revealed statistical significance for primary exposure/stressor condition.

Appendix C. Reviewers

In addition to the CPRAI Working Group members, the following individuals provided input to this Initiative and to this document specifically:

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