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LOE1-focused Ignite S&T Workshop Proceedings Maximizing Human Potential Line of Effort 1: Optimize Health & Enhance Human Performance

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LOE1-focused Ignite S&T Workshop Proceedings

Maximizing Human Potential Line of Effort 1: Optimize Health & Enhance Human Performance

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LOE1-focused Ignite S&T Workshop

Proceedings

Maximizing Human Potential Line of Effort 1: Optimizing Health & Enhance Human Performance

Introduction

The performance of Soldiers, Leaders and Senior Leaders of the future force, will be a critical factor in the success or failure of future operations. The future operational environment (FOE) of 2040 and beyond (FOE 2040+) will place unprecedented demands on these personnel, pushing them to the extreme limits of their cognitive, physical, and emotional capabilities. It will be critical to maximize human cognitive, physical, and emotional potential in future operations by optimizing the health and resilience of Soldiers, Leaders and Senior Leaders and providing safe, impactful, and ethical human performance solutions. Optimizing the health and resilience is the foundation from which to enhance human physical, cognitive and emotional performance and to ensure overmatch in the future operational environment. Optimizing and enhancing human performance will maximize individual and unit operational effectiveness within the Army's future formations.

The Army Futures Command (AFC) Maximizing Human Potential (MHP) sprint team has been tasked with understanding the human-level demands of the FOE 2040+, documenting the human performance requirements of the operational force; identifying critical areas for research; development, test and evaluation (RDT&E); and supporting the modernization of how the Army acquires, develops, and manages its personnel. The MHP operational approach defines three lines of effort (LOE):

- **LOE 1: Optimizing Health and Human Performance**
- LOE 2: Optimizing Human-System Performance
- LOE 3: Optimizing Talent Management

The U.S. Army Medical Research and Development Command (MRDC) has been designated as the lead for LOE 1. As acting LOE1 lead organization, U.S. Army Research Institute of Environmental Medicine (USARIEM, MRDC subordinate lab), with support from other MRDC subordinate labs and AFC subordinate S&T organizations (including Combat Capability Development Command or DEVCOM and relevant Program Executive Offices, Cross Functional Teams and Capability Development Integration Directorates), is working to synchronize efforts in support of the MHP mission. The LOEs have developed key milestones that include the execution of a series of activities in support of Senior Leader engagements and decision points regarding MHP efforts. These include engaging the Army S&Ts community to inform the forthcoming MHP Concept.

On 02 November 2021, the MHP effort initiated an extended discussion series with the Army's S&T community intended to inform the development of the Army Operating Concept 2040 and related Army concepts and strategies. As an integral part of MHP's ongoing Campaign of Learning, this series consisted of seminars and discussion panels focusing on development of a comprehensive picture of the science and technology (S&T) landscape within each of the three MHP Lines of Effort (LOE). Introductory workshops focusing on each of the three MHP LOEs occurred on 2 November 2021 with LOE 2, "Optimizing Human-System Performance", 8 November 2021 with LOE 1, "Optimizing Health and Enhancing Human Performance," and 17 November 2021 with LOE 3, "Optimizing Talent Management". Weekly follow-on events focused on LOE-specific topics on a

rotating basis across LOEs, with additional cross-LOE topic discussions. Discussions were critical for the MHP community to describe the art-of-the-possible within the context of the most up-to-date knowledge across the Army S&T community. This report summarizes the LOE1 focused workshops, to include the LOE cross-over workshops; and, includes additional S&T gaps and opportunities that have been discussed within the MHP LOE1 community. The outcomes will be used to inform the human performance required capabilities for the Army of 2040. The next Army Operating Concept (AOC 2040) is planned for release at the end of FY22 with related Cross Functional Annexes and Functional Appraisements in the following FY.

LOE1-focused Ignite Workshops Overview

The LOE1-focused workshops consisted of seminars and discussion panels to develop a comprehensive picture of the S&T landscape related to Optimizing Health and Enhancing Human Performance. During the first workshop series (Nov 2021-Mar 2022), there were nine LOE1 topic-focused workshops where subject matter experts (Appendix A) presented past, current and future proposed efforts related to some of the pre-identified gaps in current S&T understanding (identified in the “see ourselves” exercise and discussed herein).

Integration of Vignettes into the LOE1-focused Workshops

In addition to using the S&T workshops to inform the S&T required to achieve the required capabilities in FOE2040+, the concept work can also support the S&T community. For example, operationally-focused vignettes were a major component of defining the human level operating environment of 2040+, and performance required in that environment. These well-developed and synchronized scenarios, modelled within the future operational environment (at the human level), can support the S&T community by providing a sense of realism and will help to ground the panel discussions regarding the problems and needs of Soldiers, leaders and senior leaders.

Workshop attendees were asked to review the LOE1-focused vignettes (Appendix A and Appendix B) prior to the LOE1-topic workshop(s) and be prepared to discuss key questions:

- Overarching: what problems are apparent in the vignette and how can we help the protagonist solve problems related to health and human performance?
- How does your emerging capability [i.e., the capability that is driving the S&T within your subject matter expertise] work within this situation?
- How could we develop an emerging capability to support this situation?

Attendees were also asked to consider some the following secondary questions, such that we could improve the vignette as the workshops progressed: “How could we make this vignette more realistic (accurate and comprehensive)?” What are we working on, within the S&T space that this vignette should reflect?” The original vignette is presented in Appendix B. A revised version, to capture environmental considerations in preparation for workshops in March 2022, is presented in Appendix C.

At the conclusion of the first LOE1-focused workshop series (March 2022), the vignette will be subsequently revised to include additional characteristics of the future human-level operational environment and human performance required capabilities for Soldiers to dominate in that environment (captured during the concept development process and the first LOE1-focused workshop series). This updated vignette, and others, will be the basis for a follow-on series of workshops to further define the S&T necessary to achieve these required capabilities. The sections below provide a summary of each of the LOE1-focused workshops, to include presentations and panel discussions.

Introductory LOE1 Workshop

8 November 2021

The overarching goal for LOE1 is to maximize human physical, cognitive, and emotional potential in the future operational environment by optimizing the health and resilience of Soldiers, leaders and teams and provide safe, impactful, and ethical human performance solutions.

Strategic objectives to achieve the overarching intent:

- Synchronize - Synchronize efforts and set a collaborative approach to pursue future capabilities as defined in the concept
- Discover - discover and develop prioritized capabilities to optimize health and enhance performance of Soldiers, leaders, and teams and these capabilities will support the performance requirements
- Deliver - facilitate integrated solutions across the AME and accelerate delivery and integration of concepts, technology, and capabilities across the DOTMLPF-P

Synchronize

Line of effort 1 has coordinated across the human health and performance communities (i.e., LOE1 member organizations) in order to synchronize language and develop a general framework by which organizations will work to optimize health and enhance human performance (Figure 1). This framework integrates human health and performance communities that drive priorities and supports force aim points and the required capabilities in the forthcoming MHP concept. The Venn diagram on the left shows the dynamic interplay between individual/team traits and states and the environment and how our understanding of those relationships inform innovative solutions/interventions that lead to optimizing health and enhancing human performance (which ultimately maximizes human potential of Soldiers, leaders and teams). The circle arrows articulate the continuous back and forth between stressor/traits/states and solutions.

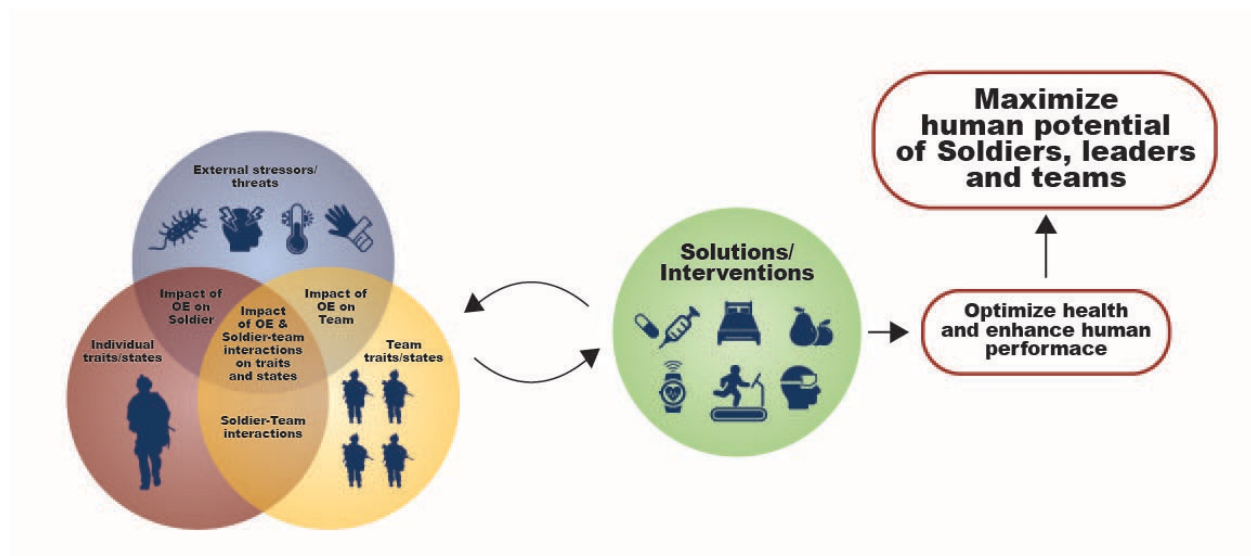


Figure 1. General framework for optimizing health and enhancing human performance.

Discover

Discovering and developing prioritized Soldier, leader and team optimized health and enhanced performance capabilities encompasses the following action items:

- Utilize cross-cutting, state-of-the-science domains (Figure 2), including current and potential future capabilities, necessary to optimize and enhance health and performance.
- Develop future OE-critical knowledge and understanding of human health, resilience and performance within and across these cross-cutting domains (Figure 2). Human performance is influenced by multifaceted, interrelated cognitive, emotional, and physical factors and dynamic settings that include wide-ranging environmental conditions (heat, cold, altitude, subterranean, urban), operational stressors and occupational exposures (e.g., injury, disease, hazard exposure). These factors will be considered as we work to address the capabilities and requirements for optimizing and enhancing health and human performance in 2035+.
- Inform requirements development through identification of key human considerations (e.g., knowledge skills and abilities, limitations, etc...) to perform in the future operating environment 2035+. This includes informing LOE 2 and LOE3 regarding these validated human centric requirements for optimizing and enhancing performance and the development of materiel and non-materiel solutions.

IN ORDER TO MAXIMIZE HUMAN PERFORMANCE FOR OVERMATCH IN THE FUTURE OPERATIONAL ENVIRONMENT, WE MUST...

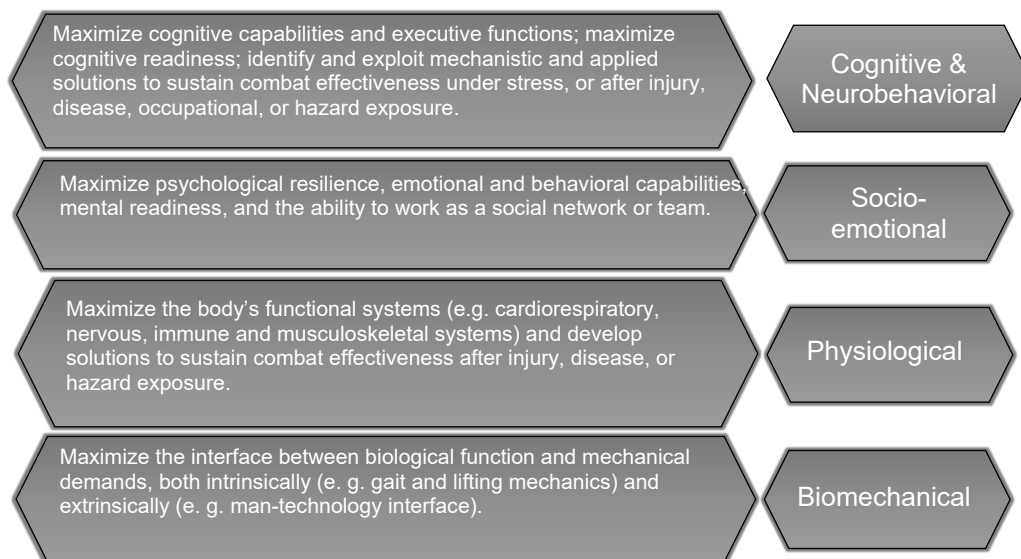


Figure 2. Cross-cutting state of the science domains for optimizing health and enhancing human performance.

These scientific domains (Figure 2) are considered in the context of states and traits and we are working to optimize/enhance these multi-dimensional states, while considering the individual's inherent traits/characteristics in each domain to maximize human performance to dominate in the future operational environment. These domains are multi-dimensional and interrelated, i.e., they interact with one another holistically and they are influenced by an individual's historical status (e.g., each individual has their own baseline that shapes their capacity in these areas).

Figure 3 expands on the framework (Figure 2) by showing the traits and states of the Soldier in the red circle, to which we apply solutions/strategies (in the yellow circle) in order to mitigate or reverse injury/performance decrements, optimize health and enhance performance. These are just some of the solutions that we may apply to positively impact human performance. Organizations are focusing on nutrition and microbiome manipulation, pharmacological interventions, some are developing assessment and training tools, leadership/team focused solutions, neuromodulation to enhance training and performance outcomes and a variety of other enabling technologies and biomeasures to optimize and enhance operational performance. These all operate in the context of external stressors and threats. In summary, we are manipulating the states to achieve an optimized/enhanced performance, with the overarching goal to optimize and enhance operational performance for overmatch.

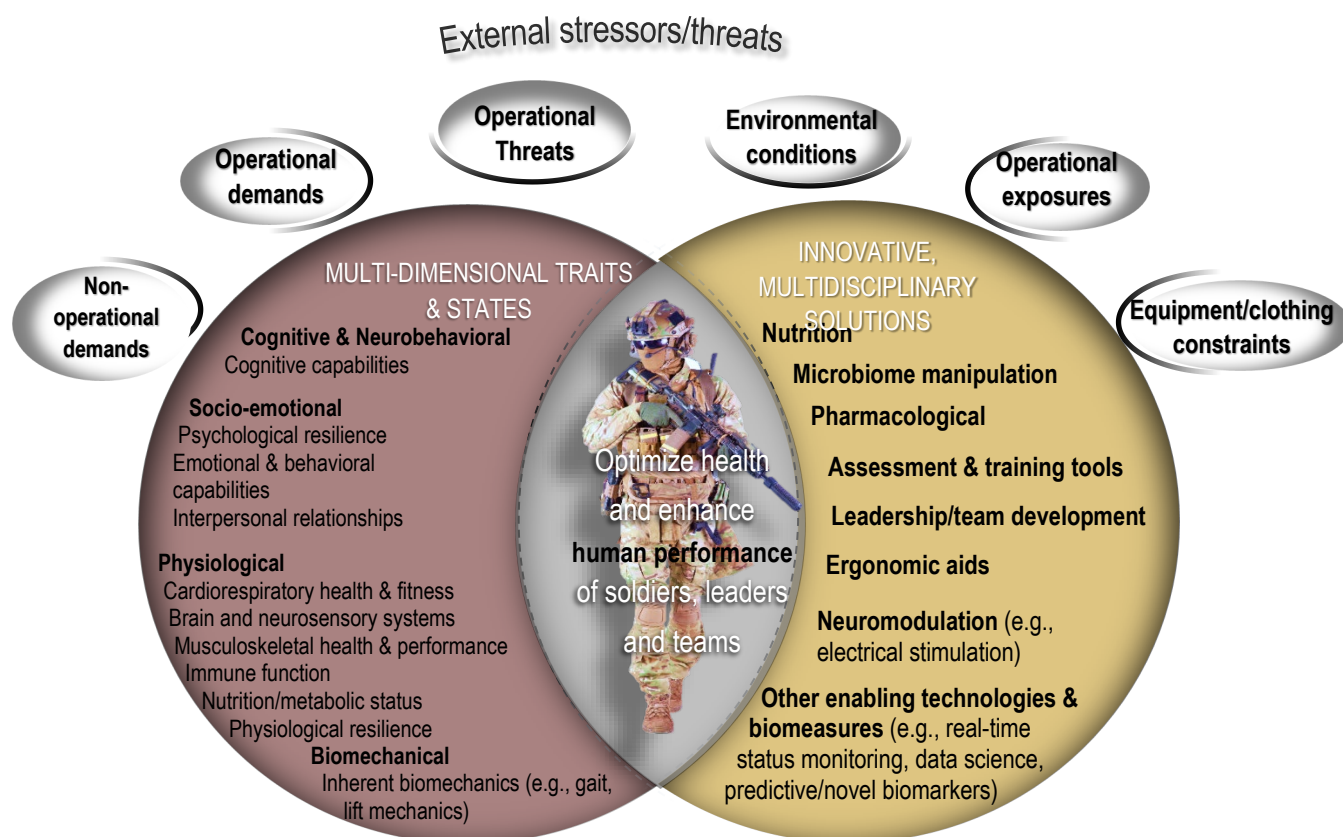


Figure 3. Detailed framework for optimizing health and enhancing human performance.

In terms of discovering and developing capabilities, LOE1 is particularly focusing on two S&T gaps and opportunities discussed prior to, and during, the 2020/2021 “see ourselves” exercise (Smith et al., 2021).

- 1) Further development and validation with regard to accurately assessing, quantifying, and predicting operational performance for individuals and teams to inform actionable decisions. This involves development of validated metrics of operational performance both at the Soldier and Small Unit level. These will allow for testing the efficacy of human performance solutions/interventions. Additionally, this objective includes the development of novel approaches and analytic techniques (e.g., machine learning

and artificial intelligence) to better understand the relationship between human health, traits, states and performance outcomes.

Example gaps in current S&T understanding under this broad S&T objective:

- What are the validated metrics of operational performance?
- What biotech tools can we use to assess health and performance risk (e.g., functional fabrics, acoustic sensors, digital twin real-time modeling)?
- How can we use novel approaches and analytical techniques to identify relationships between human health, physiology/neurobiology, attributes, states and performance outcomes?
- What are the emerging relationships between human health, physiology/neurophysiology, attributes, states and performance outcomes?

2) Preventing and mitigating (or reversing) health and performance decrements, and enhancing multiple aspects of performance, in order to maximize and sustain lethality of the Force. We'll do this with validated and targeted scientific solutions.

This focus area includes optimizing health and optimizing or enhancing human performance which requires us to directly apply established, emerging, and pioneering scientific solutions to the Soldier, leader and/or team. These solutions integrate across multiple scientific domains and identifying and implementing these solutions will require multidisciplinary, collaborative efforts between military, academic, and private sector scientists.

Example gaps in current S&T understanding under this broad S&T objective:

- How can we enhance injury and disease resistance to novel biophysical threats and unanticipated exposures??
- How can we enhance mental endurance in the face of intense, rapidly changing, fatiguing conditions?
- How can we create hyper-mindful Soldiers who can self-regulate and persevere under extreme stress?
- What training approaches can we use to optimize and enhance cognitive and physical capabilities?
- What innovative approaches (e.g., neuromodulation, pharmacology, nutrition, etc...) are effective and safe for enhancing cognitive and physical capabilities?
- What innovative approaches (cross-adaptation) are effective for optimizing and enhancing performance in operational extremes (e.g., Arctic, urban)?
- How can we expand and enhance unique capabilities of the modern, digital-generation Soldier?

Cross-LOE coordination in addressing these gaps and opportunities will provide critical opportunities to leverage LOE-specific S&T investments to jointly address capabilities defined in the Army concepts.

Examples of synchronization opportunities between LOE1 and LOE2 (Optimizing Human-System Performance): LOE1 provides the science basis for human-system integration efforts (e.g., providing design guidance to head-borne system developers and delivering scientifically-grounded recommendations and knowledge products for human-centered augmented reality information display and innovative tools and applications). Physical Augmentation is another synchronization area between LOE1 and LOE2, wherein LOE1

efforts feed into technology for human interactions and physical augmentation (PA), i.e., highly effective and adaptive PA systems that significantly increase Soldier performance and understanding adaptation to systems and movement intent for advanced controls. Additionally, leveraging sensors and non-human systems, where current efforts are embedding sensor technology into mission planning and execution software (future possibility: think google maps inserted into heads-up display to identify “best route”). Lastly, future vertical lift program is adding human monitoring capabilities to next generation aircraft (to include health monitoring)¹, which optimizes human-system effectiveness (e.g., real-time info sent to onboard autonomy system for decision making to optimize status).

Examples of synchronization opportunities between LOE1 and LOE3 (Optimizing Talent Management): near-term LOE1 efforts are identifying the key metrics that need to be measured to quantify and predict individual and unit readiness (performance optimization), performance in the context of Soldier tasks, and resilience (physiological, psychological and cognitive). Each of these key areas synchronize with the Talent management pillars. For example, LOE1 efforts to measure and predict readiness and performance synchronizes with Talent Management efforts, wherein fitness evaluation and assessment is part of the framework and, the solutions of these LOE1-related efforts (e.g., technologies, algorithms and decision aids) can specifically inform the development of methods and tools to enable the Army to employ the right individual in the right job and right team, at the right time to maximize the effectiveness of each Soldier and team (LOE3). These findings may also inform the development of training, education and other approaches to help ensure that every soldier and leader can reach their full potential. Additional, LOE1’s work in predicting resilience (physiological, psychological and cognitive), produces models and metrics that may be used by leadership and medical professionals to identify factors (biological, physiological, demographic, genomic, psychological) that can be manipulated through nutritional, training, or other interventions to improve training outcomes and reduce injuries. These products, again, inform the development of training, education and other approaches to develop the force as well as retaining talent. Also related is enhancing training efficiency, wherein LOE1 efforts underpin the science basis of learning (i.e., learning and performance from a neuroscience perspective) and developing related training tools to optimize learning, which aligns with talent management’s integrative system to train and organize military personnel.

Deliver

The last strategic objective of LOE1 is to “deliver”, which involves creating and leveraging opportunities to overcome barriers to transitioning Soldier and leader health and performance solutions and technologies across the DOTMLPF-P.

There are three initiatives in order to facilitate delivery of these solutions and technologies:

- 1) Identify and engage transition partners to develop and prioritize technical objectives to facilitate achievement of the LOE objectives. This involves reducing barriers to transition and speed delivery of concepts, technology, and capabilities to meet validated end-user requirements.
- 2) Maintain active engagement with industry, academic partners and other government entities to identify and develop the most promising health and performance solutions and technologies. This involves developing methods and approaches to both stay abreast of, and to evaluate, emerging technologies as potential solutions; and, maintaining active market research (e.g., technology landscape mapping) and

alternatives analysis based on ongoing engagement with academia, industry, and other government efforts

- 3) Identify and engage product developers and other transition partners early in the research process to ensure that potential solutions address critical operational performance requirements, are not duplicative of on-going PD efforts, are operationally suitable, and can transition efficiently and effectively. This involves ensuring research is designed to assess manpower and end-user requirements (credentials, training, etc.) to enable adequate support for the capability; ensuring research is designed to incorporate mitigation strategies for potential environmental, maintenance and sustainment constraints, if applicable for planned environment; and, ensuring early research and development testing are designed to assess performance and operational needs with defined go/no-go decisions points that enable early candidate down-selection.

Developing & validating metrics of operational performance and methods to monitor and assess cognitive capabilities in operational/training environments

15 November 2021

This session was moderated by Dr. Tracey Smith (Lead, LOE1) and Dr. Tad Brunye (Neuroscientist, DEVCOM-Soldier Center or DEVCOM-SC).

MASTR-E 72-h Field Study (Ms. Victoria Bode, DEVCOM-SC)

Measuring and Advancing Soldier Tactical Readiness and Effectiveness (MASTR-E, Figure 4) is a 5 year 6.2 and 6.3 effort funded by Army and OSD-funded effort to measure, predict, and enhance Soldier and squad close combat performance. In terms of training, MASTR-E seeks to quantify aspects of individual and collective lethality, increase collective performance during exercises with actionable information and increase marksmanship performance under stress. From an operations standpoint, MASTR-E seeks to monitor physiological status to inform lethality ratios and maintain performance on the objective with actionable information. Lastly, in terms of acquisition, MASTR-E seeks to develop metrics and methods to objectively evaluate the effect of new clothing and individual equipment (CIE) on Soldier and Squad performance, using more realistic simulations for decision making and testing methodologies.

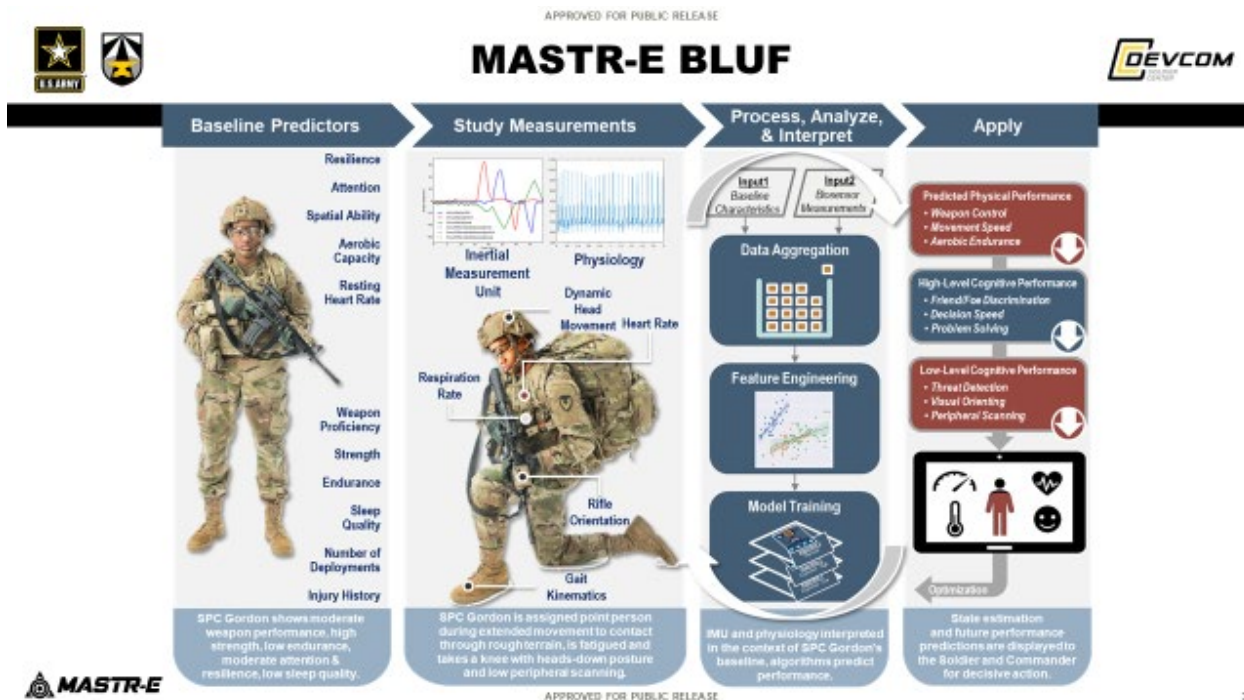


Figure 4. Overall scheme of MASTR-E program

The overall MASTR-E program ideal starts with a baseline of the Soldier at one point in time, where state and trait factors are collected. The Soldier moves into a MASTR-E sub-study, where various study measurements are collected (e.g., inertial measurement units, physiological biomarkers, gait kinematics, etc.). Together with the baseline data, collected data is then processed, analyzed (using traditional methodology and machine learning

methodology), and interpreted to create predictive models that can apply to operational settings and subsequently incorporated into Army training to enhance Soldier lethality and mitigate degradation.

The '72-h Field Study' (72HFS) is a MASTR-E sub-study using a sustained operations model. The models developed within 72HFS will feed the overarching programmatic goals by providing the sustained field operations data to help strengthen the diverse approach to modeling utilizing field and lab data for individual, squad and platoon elements. The objectives of the 72HFS are to identify the human dimension 'X-factors' that reliably account for dismounted Soldier and small unit performance on fundamental warfighting tasks *during sustained operations*; and, outcomes are to provide objective, quantifiable means to assess operational performance areas to supplement existing evaluation methods and status reports.

There are two specific aims within the 72HFS:

- 1) Field tools to detect and manage Soldier performance changes during sustained operations

Deliverables include field collection methodology, data visualization tools, and reports about performance under sustained operations. Repeatable methodology to measure and detect Soldier performance decrements during sustained operations includes a combination of objective and subjective measures, inputs from self-, peer-, and expert-assessments, quantitative and qualitative approaches, tasks centered on individual, fire team, squad, and platoon level evaluations, and all suited to field conditions. The broader impact of this work is to add an objective measure to commander and NCO intuitions and display this information in the form of dashboards and decision aids, inform human performance testbeds for next-generation technologies, enable longitudinal tracking of training outcomes over time, and provide methodology to utilize as a training scenario and intervention platform.

- 2) Data and analysis tools to increase future capabilities in the battlefield (i.e., anticipate performance decrements; iterate with M&S approaches)

Deliverables include human performance data, measures and metrics, and predictive algorithms. For example, predictive algorithms determine operational success from baseline profiles and down-selected x-factors that anticipate performance during sustained operations. Realizing the surge in machine learning/artificial intelligence advancements, the algorithms aim to predict meaningful trends in Soldier performance from baseline measures and to down-select inputs to a reliable, non-redundant set and are intended to determine the combination of baseline characteristics that correspond to meaningful mission performance. The broader impact of this work is to manage performance decrements before they give rise to critical failures, determine metrics to prioritize in next-generation kit and equipment, inform selection criteria by anticipating risky vs. ready individuals, and enable future modeling and simulation efforts.

Soldier Outcomes of the 72HFS include objective performance outcome quantification tools to supplement the assessment and evaluation of multi-day close-quarters combat drills; guidelines on performance focus areas to enable readiness and effectiveness of key outcomes, and infrastructure to store, access, and visualize human performance data trends based on relevant criteria and attributes to guide training, strategy, and selection. Technical Objectives include identifying quantitative and qualitative metrics to evaluate and monitoring performance during a multiday live fire training exercise, providing a front-end interface of the human performance database to enable data trend visualization and the validation of human performance prediction

algorithms, and down-select baseline metrics that predict sustained dismounted Soldier/Squad performance, including holistic assessment suite and data analytic tools and algorithms.

Ms. Bode presented methods for the 72HFS. In terms of analyzing Soldier performance data, the study uses two common approaches. The first is a hypothesis driven approach, e.g., identifying mediators of performance changes from pre to post mission, and assessing intra-mission changes in performance. Additional data is necessary to answer hypothesis driven questions with the next data collection occurring June 2022. The second is data driven, exploratory approaches to capitalize on rich datasets to understand how baseline traits and the multi-domain measures of performance are related and interact to influence performance outcomes. The goal is to predict future performance, as well as identify current state of a Soldier at both the individual and squad level, the latter of which is lacking in the literature. To demonstrate these capabilities, we predict marksmanship performance on the 72HFS Simulated Marksmanship (SIMARX) course and developed a preliminary model to “predict marksmanship performance for pre-mission, and post-mission field events. At the outset, we show that baseline measures may be used to predict marksmanship over time. For example, pre-mission performance is predicted by a number of cognitive measures, (e.g., attention, spatial perception, and decision-making), whereas post-mission performance is predicted by cognitive, as well as physical performance metrics.” As the team continues to receive and process raw data, these models will become more expansive and robust.



Figure 5. MASTR-E Predictors and Outcomes

This modeling approach will be applied to the other operational domains critical to Soldier performance, including Move, Sustain, Navigate, and Communication (Figure 5). Future directions of this work include focus on degradation of the Soldier over time and measures of lethality, identify unique combinations of features that better classify sub-populations, define aggregated domain scores (physical, health, socio-emotional, cognitive), and prediction-constrained factor analysis for interpretable predictions of Soldier performance.

Validating predictors of success during military training (Dr. Emily Farina, USARIEM)

USARIEM Military Nutrition Division (MND)-led field studies to predict success include: 1) Selection course, which is a prospective study of factors associated with career success among Soldiers in Special Forces training. Enrollment is complete and follow-up is ongoing; and, 2) Training Course, which is a cross-validation of factors associated with resilience and performance among Soldiers undergoing 22-weeks of Infantry One-station Unit Training (OSUT). This work is in the planning phase and undergoing approvals to implement.

Objectives of the SFAS study include: identifying factors related to successfully completing Special Forces Assessment & Selection (SFAS), the Special Forces Qualification Course (SFQC) & remaining on active duty (up to 20-y follow-up); identifying factors related to experiencing injury and illness during military careers; and, describing changes from pre-SFAS to post-SFAS and post-SFQC. Predictive factors include psychological, physiological, nutritional, demographics and life experience measurements. Short-term training outcome include selection performance, illness and injury (during SFAS); and, graduation, illness and injury (during SFQC). Long term outcomes (20 yr follow-up), include retention, injury and illness (assessed at 2, 5, 10, 15 & 20 yrs).

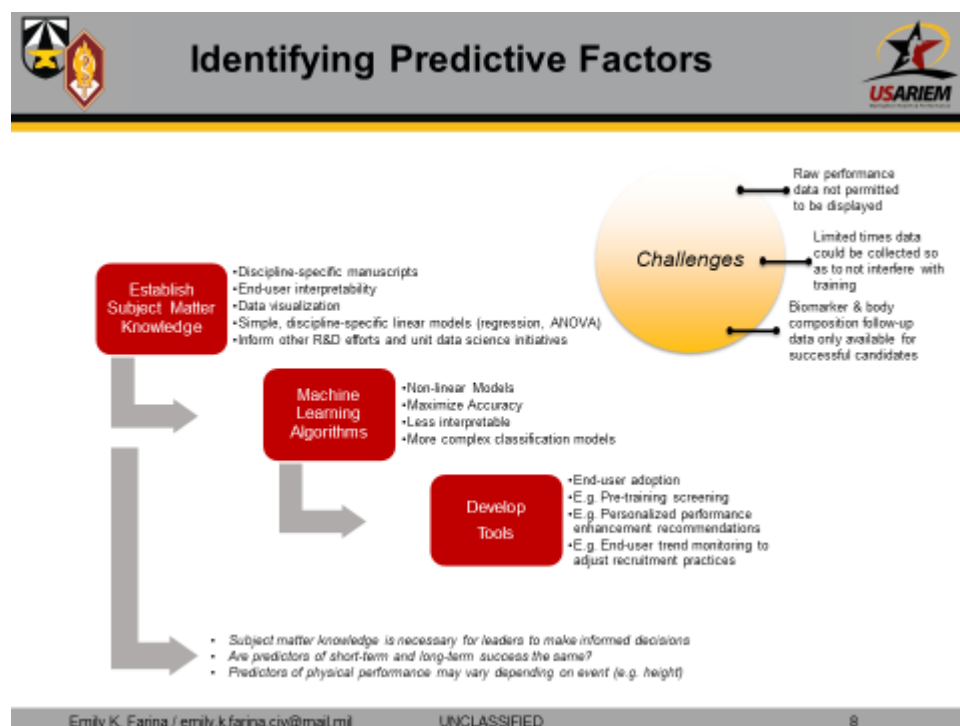


Figure 6. Methods for Identifying Predictive Factors for SFAS Training

The summary methods for identifying predictive factors include establishing subject matter knowledge, machine learning algorithms and development of tools (Figure 6). Subject matter knowledge is necessary for leaders to make informed decisions and key features include discipline-specific reports (Farina et al., 2019; Farina et al., 2020; Farina et al. 2021; Knapik et al., 2020), end-user interpretability, data visualization, simple discipline-specific models and the ability to inform other research and development efforts and data science initiatives. Machine learning algorithms consist of non-linear models and more complex classification models; and, while they maximize accuracy, they are less interpretable (compared to linear models). Examples of end

user tools for eventual adoption are pre-training screenings, personalized performance enhancement recommendations and end-user trend monitoring to adjust recruitment practices. Challenges of conducting a study in this environment include limited times for data collection so as not to interfere with rigorous training, inability to show raw performance data and follow-up biomarker and body composition data is only available in candidates who successfully completed the training.

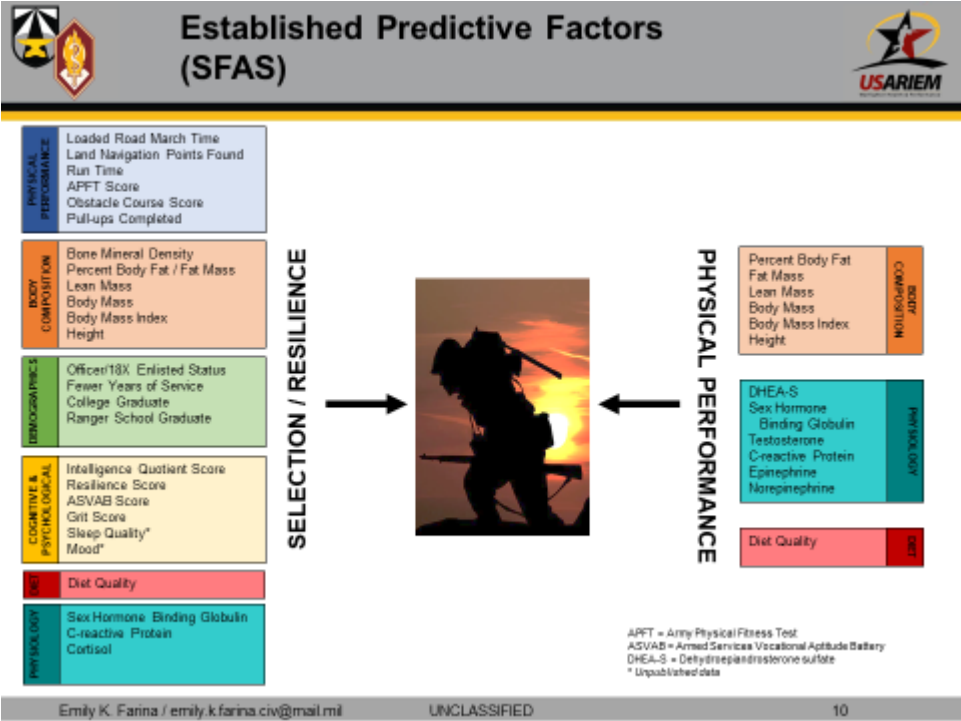


Figure 7. Established Predictive Factors for SFAS Training

Results indicated that multiple factors predicted selection/resilience (physical performance metrics, body composition metrics, demographic variables, cognitive and psychological metrics, diet quality and physiological biomarkers) and physical performance (body composition metrics, physiological biomarkers and diet quality) (Figure 7). In terms of physical performance, the most predictive metrics were faster times for the first and second road march, land navigation, the first and second run time, and the obstacle course; and, higher scores for the Army Physical Fitness Test and pull-ups.

A future study aiming to cross-validation physiological, nutritional and psychological factors that predict resilience and performance among Soldiers participating in OSUT and characterize longitudinal changes in these factors throughout OSUT is undergoing planning. Factors under assessment will include anthropometrics, body composition, physiological biomarkers, nutritional factors and psychological factors with the goal to predict measures of resilience, physical performance, tactical performance and injuries and illness. This study will use growth modeling to identify individual trajectories of change during training, will have greater generalizability to a broader Army population (compared to the SFAS study discussed herein) and may identify Soldiers at risk for adverse outcomes that may benefit from additional training, support and/or interventions.

Panel discussion

Attendees indicated that it was helpful to consider their research efforts in the context of the realistic situation presented in the vignette. Observations from the panel discussion regarding the vignette itself, and integration of the vignette into capability development, follow.

Observations from the vignette are presented below and also captured in Appendix D:

- The group is operating in conditions of uncertainty
 - Directly applicable to Dr. Farina's presentation (SFAS data and environment), Soldiers must meet standards in uncertain conditions. By identifying predictors of success in that environment, we can develop performance screeners perhaps that could be administered before entering the environment to enhance performance, e.g., work on behavior change related to sleep quality.
- Protagonist has mud on the goggles which leads to reduced visibility
- Sore neck from poor posture
- Force tracker not updating; no updating status
- Interpersonal challenges (echelon based;
- Severe lack of sleep and poor quality when they could sleep
- Status tracker and everyone was in "red" and someone wasn't updating at all
- Towards the end, escalation of interpersonal conflict
- Opportunity for sleep at the end that was cut short

Additional considerations to make the vignette more realistic:

- Further expound upon the environmental extremes and hydration issues
- Modernize the technology that is being used in the field
- Consider adding more stressful conditions, e.g., in an operational environment, units may be more "on the offensive" (received and sending fire), which leads to a highly pressurized situation.

Both of the speakers discussed some of the potential biosensing capabilities and metrics that may be used to assess the potential for individuals and teams to perform optimally. Challenges in the techniques for analyzing this type of data, in general, is that when the data is aggregated we see the trends/big associations and it is more challenging (and necessary) to assess at the individual level, i.e., which performance outcomes are most likely to be negatively impacted (e.g., decision-making skills may be more important in some scenarios versus perceptual motor skills). Additionally, what is the practical importance of Soldiers being "in the red", in terms of the status tracking? That is, it is unclear how these observations are tied to performance outcomes. Both of the talks today speak to some of the potential metrics and biometric metrics predictive of performance indices, but we also need to consider the actual performance requirements to dominate a specific situation: 'Measures of Performance' (MOP), performance of critical tasks in the context of 'Measures of Effectiveness' (MOE), the tasks that are the most critical for our Soldiers, leaders and senior leaders. This is an area that requires further discussion and elucidation, e.g., identify the impact of the FOE on human level performance, and the degradation of that performance on formation success (MOEs) and the subsequent MOPs. Importantly, identifying how we can prevent units/individuals from going into the red even before it impacts performance. Lastly, it was mentioned that the SFAS prospective study results (predictors) can be used by the MASTR-E team to structure first pass hypotheses for the MASTRE data set.

Identifying and assessing efficacy of synthetic biology; biotech tools to assess health and performance risk

6 December 2021

This session was moderated by Dr. Tracey Smith (Lead, LOE1).

Functional fiber-based edge computation and inference to optimize Soldier health and performance (Dr. Reed Hoyt, USARIEM)

Dr. Hoyt covered wearable systems, the system elements and highlighted two new functional fibers capable of sensing temperature and sound that bring innovative capabilities to the forefront. Wearable technologies have historically been used for data collection for post-hoc after-the-fact analyses. It's a powerful approach because we can instrument large numbers of Warfighters in various settings and collect valuable information regarding their health and performance states without interfering with Soldiering activities. However, development of wearable systems that are capable of collecting and interpreting sensor data in real-time presents added challenges, to include SWaP-C (size, weight, power and cost), scalability, acceptability, maintaining accountability, ease of use, open architecture, and system integration. Additionally, wearables collect a huge amount of data, making it necessary to process and cull data on the spot and communicate only actionable information. Use of wearable systems in operational environments, compared to a training environment, presents further challenges; however, successes have been noted in Iraq and Afghanistan where data collected during combat operations has helped guide changes in doctrine to reduce heat strain. Altogether, these aforementioned challenges can be overcome to reap the benefits of wearable technologies for optimizing health and performance of Warfighters.

Many physiological monitoring systems, originating from MRDC, have been proven successful, or are undergoing evaluation, to predict and manage heat strain and/or work strain management. Three examples are NGB CST-WMD CBRNE teams – Equivital EQ02 and the HIPS - Heat Injury Prevention System (chest strap-based systems)), and the LifeLens Ascent system (miniature, adhesive).

One of the original physiological monitoring systems is the commercial off the shelf (COTS), semi-open architecture, FDA-certified Equivital EQ02, which is being deployed to National Guard's Weapons of Mass Destruction Civil Support Teams. Heat strain is a common problem when wearing encapsulated CBRNE protective gear and this system works to mitigate that risk, via monitoring of ECG, respiratory rate, accelerometry, skin and estimated core temperatures. Drawbacks include complexity in setting up and use, sizing the chest harness (9 sizes), high cost, and limited battery life (48 hours). The user must provide the wireless off-body data link.

Another physiological monitoring system is the Government owned, open-architected Heat Injury Prevention System (HIPS) which is being used within the Ranger Assessment and Selection Program (RASP) to provide real time heat strain/work strain monitoring of RASP participants. The HIPS system senses heart-rate, body motion (accelerometry), and skin temperature and estimates core body temperatures and thermal strain. The information is sent to hand-held devices and to the medic or command post on the training routes.

At the forefront of current efforts in wearable technology is the Lifelens Ascent system (Figure 8), the centerpiece of the Health Readiness and Performance Systems (HRAPS) Program of Record (U.S. Army Medical

Matériel Development Activity, MRDC). This system consists of a tiny sensor device (a 5 gram “Hub”) that sits on an adhesive and allows for collection of data that is resistant to motion artifact. This heat-strain monitoring system has overcome many other challenges that present with wearable physiologically monitoring systems to include, size (miniature, low profile adhesive sensor units) and logistical feasibility (reusable, water resistant, skin safe and can be work for 72+ hours).

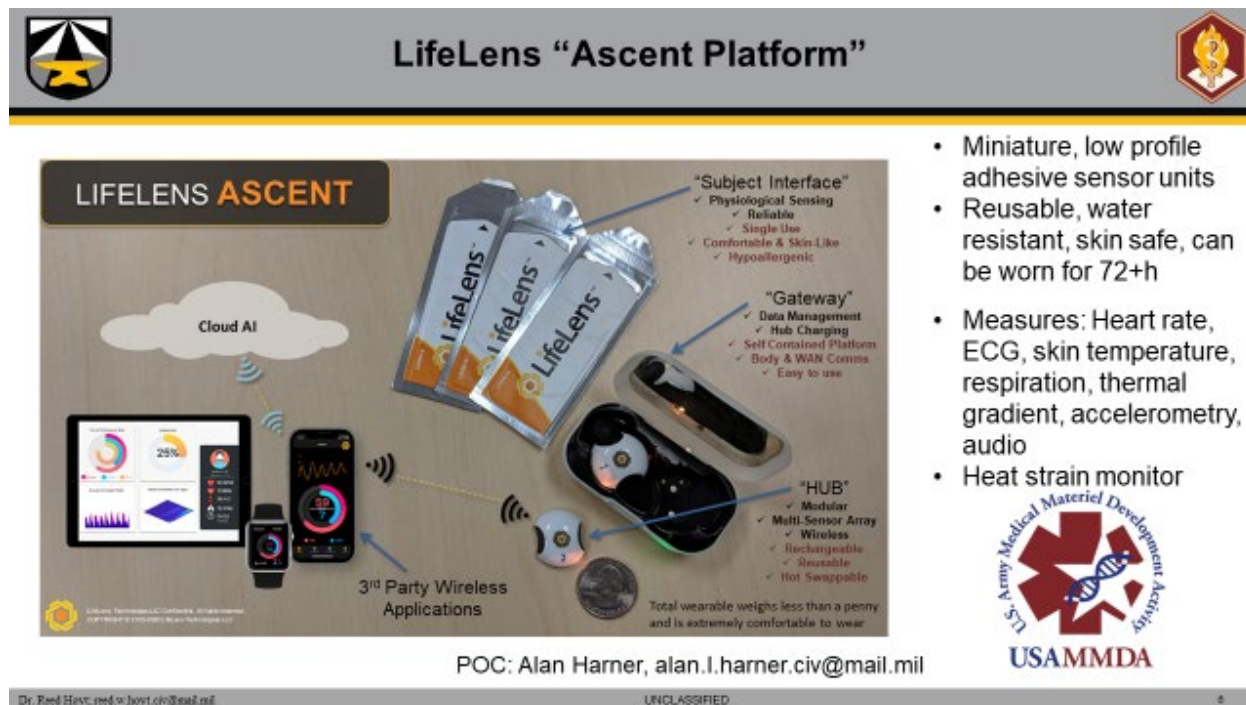


Figure 8. LifeLens "Ascent Platform"

Prior mentioned wearable systems continue to present challenges in terms of scalability and deployment (e.g., cost, cyber security and integration). Two new, recently developed functional fibers that have emerged from work at the Massachusetts Institute of Technology Institute of Soldier Nanotechnologies, and the Advanced Functional Fibers of America non-profit, bring innovative capabilities to the forefront: a ground-breaking fiber in fabric microphone (Yan et al., 2022) and a RFID fiber temperature sensor (Loke et al, 2020). Both of these fibers promise to overcome many of the challenges that accompany wearables for real-time situational awareness of health and performance, e.g., they reduce system SWaP-C, are unobtrusive, scalable and can be tailored to meet dynamic mission needs. These technologies will ultimately transform uniforms from clothing goods to a platform technology of programmable services through sensors and multifunctional chips in fibers. The ultimate vision is that computing fibers will be field programmable and tailorable to meet dynamic mission needs.

Fiber- and Fabric-based Acoustic and Temperature sensing for Soldier Physiological Monitoring & Threat Detection are shown in Figure 9. Wireless, battery-less temperature sensing RFID fibers, once woven into textiles, and are unobtrusive and difficult to detect. These fibers are particularly useful in arctic deployments and training where participants are at significant risk for peripheral cold injury, which may result in permanent nerve damage and loss of tissue. This RFID fiber technology will enable the medic to query temperature sensors woven into socks and gloves, and thus identify Soldiers with extremities (e.g., fingers, toes) at risk of

freezing cold injury, and intervene to mitigate the risk of frostbite. This technology is scheduled to undergo field testing during the 2023 winter/spring season.

Acoustic fibers in fabric (<https://www.nature.com/articles/s41586-022-04476-9>) will help ensure the health and performance of Soldiers by enabling inward physiological sensing (heart sounds, respiration, voice, etc.) as well as outward environmental sensing (speech, harmful noise, gunshot detection, etc.). This technology uses thin, lightweight, flexible, rugged, scalable (hundreds of meters in length in a single manufacturing run), affordable fiber microphone that is woven into fabrics. These beneficial characteristics overcome many of the aforementioned challenges to wearable physiological monitoring devices. It is estimated that large scale test and evaluation will occur in approximately two years.

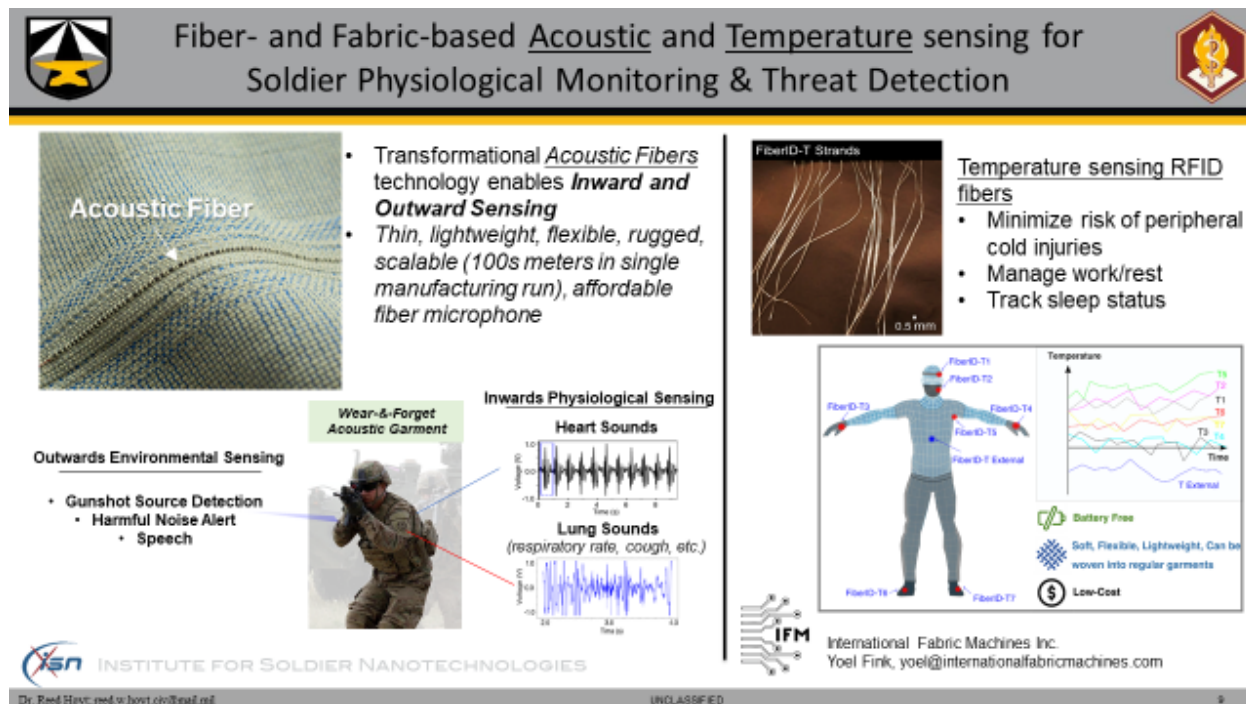


Figure 9. Fiber- and Fabric-based Acoustic and Temperature sensing for Soldier Physiological Monitoring & Threat Detection

Emerging biofluid based physiological sensing platforms- science and future applications (Dr. Matt Coppock, DEVCOM-ARL)

Biomarkers are biological molecules found in blood and other bodily fluids or tissues that is a sign of a normal or abnormal process, or of a condition. When we talk about biomarker versus symptom comparison, biomarkers can be pre-symptomatic and more insightful than physiological monitoring. The human body's responses to short and long term stressors appear as changes in various biomarkers in the body. Outward physiological symptoms are responses to biomarker shifts within the body and provide these advantages:

- Biomarker responses are not masked by ego.
- In some cases, biomarker shifts occur long before outward physiological responses present themselves; e.g., early notice of immune compromise translates to rapid treatment and recovery.

- Subtle responses appear in biomarker shifts that may never present themselves as outward physiological signs, e.g. changes in mood, alertness, and metabolism (nutrition).

Biomarkers provide a link to actionable information related to exhaustion (metabolic), alertness, musculoskeletal injury, infection (natural and weaponized), chemical exposure, emotional instability, recovery, hypoxia, dehydration and heat and cold stress. Understanding the linkages between biomarkers and fluctuations (e.g., circadian and in response to stressors), and how these biomarkers can be used to provide valid, relevant and actionable information is key. The expansion of biosensing platforms provide a tool for rapidly detecting biomarkers during training and operations; however, application in a research setting is a potential benefit, e.g., assess biomarkers in real-time for the purpose of mapping to Soldier-relevant outcomes (e.g., identifying metrics of successful operational performance and risk factors for degraded performance).

The objective of this effort is to develop wearable sensor arrays for measuring chemical and biological agents in biological fluids (e.g., sweat), air and vapor. These biofluids are least invasive and not difficult to prepare, compared to blood; however, the tradeoff in using these biofluids is that the concentration of biomarkers is lower, and the presence delay is higher. Interstitial fluid may be a viable consideration, however, with that said, the aforementioned benefits of saliva and sweat likely outweigh the tradeoffs.

The payoff of developing wearable sensor arrays for measuring chemical and biological agents in sweat, air and vapor is that Soldiers will be able to track their performance before symptoms are noticeable, and may be rapidly alerted to threat exposure before damage or injury. There are chemical and biological applications for this technology (Figure 10). This technology will give squad leaders actionable information about their team's individual warfighter readiness and increases the rate of decision making in high tempo engagements. E.g., sustain- know when to push harder, recovery, and stay alert to keep up the pace; prevent and treat- know before Warfighters succumb to illness, how to prevent or treat with a limited medical kit, and track recovery; and, improve- learn warfighter's response to stressors during training to improve performance and select team members and supplies tailored to each mission.



WEARABLE BIOMARKER MONITOR



Objective: Develop wearable sensor arrays for measuring chemical and biological agents in sweat, air and vapor

Payoff:

Soldiers will be able to track their performance before symptoms are noticeable, and be rapidly alerted to threat exposure before damage or injury

Applications

Chemical	Biological
- Industrial process monitoring/control - Leak warning and mapping - Wearable: Exposure warning - Water quality (toxins)	- Wearables (non-invasive, invasive, & alert): Metabolite, Glucose, Vitality, Biohazard exposure - Water quality (pathogens)
- Chemical residue testing (e.g. crime forensic, explosives, chemical weapons) - Pharmaceutical & illicit drug testing	- Health diagnosis - Food quality - Foodborne pathogens - Biometric authentication

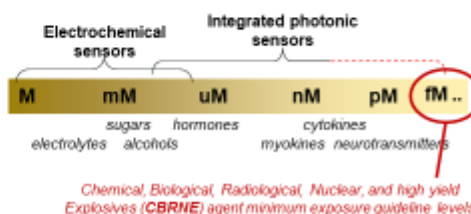
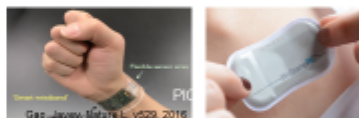
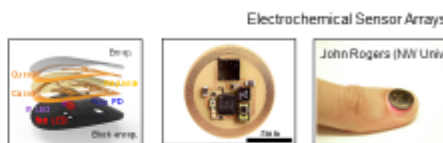


Figure 10. Wearable Biomarker Monitor

Biosensor makeup. Bioreceptors are integrated into the transducer (i.e., electrochemically-, photonics- or colorimetric-based) to provide a selective attachment to the bioreceptor of choice to ultimately produce a measurable signal. The key feature of the bioreceptor is the ability to selectively pull a biomarker out of a complex solution, such as a biofluid. The traditional gold standard is antibodies, however, they exhibit limited performance in operational conditions (e.g., not very stable, expensive to make) and alternatives exist. Current work is ongoing with regard to photonic integrated circuit (PIC) development, a specific transducer technology on which bioreceptors can be integrated. Benefits include size, weight, cost component; has hundreds of sensing areas on the chip (allowing detection of multiple biomarkers at once); and, are sensitive to concentrations as low as parts per million/billion. Ruggedized bioreceptors are also under development, called protein catalyzed capture (PCC) agents which are 1/40th the size of antibodies and use the same building blocks, but have benefits making them cost-effective (e.g., on-demand synthesis at half the cost of antibodies) and useful in operational conditions (e.g., easily functionalized for sensor integration, thermally stable and biologically stable).

In summary, monitoring of internal biochemistry can provide in-depth physiological information, complementing external sensors (e.g. heart rate, eye tracking); PICs can be carried on person or mounted on equipment; PIC sensors are modifiable for biological and chemical agents; and, can be multiplexed to carry hundreds of sensors in a few millimeters of space. Near-term questions for consideration include what biofluids to monitor and what specific biomarkers to target with this technology.

Synthetic Biology Enhanced Sensing to Enable Soldier Health and Performance Resiliency (Mr. John Player, DEVCOM-SC)

Army Futures Command has released a series of S&T strategies to guide S&T over the next ~15 years. One of these strategies centers on Synthetic Biology for both novel materials applications and human performance/protection enhancements. The later piece of the Synthetic Biology strategy is known as the Synbio HeAlth, Performance and Extended Survival Kit (or SHAPES Kit). This product centered “kit” seeks provide unprecedented and game changing ability to predict, optimize and sustain Soldier health, performance and resilience. A central focus is to maximize performance and survival during prolonged expeditionary operation, all enabled using current and future synthetic biology technologies. The SHAPES kit consists of three components: 1) A physiological and health status monitor; 2) interventions to optimize, enhance, sustain performance; and, 3) a decision aid.

The purpose of the **SHAPES Physiological and Health Status Monitor** is to provide real-time sensing of Soldier physical, cognitive and health states, individualized whole body personalized state, sensing at point of need and health and performance knowledge for decision support. Features include whole body networked biosensors, personalized biosensors developed on-demand, biological health and performance state sensing, lab quality bio analysis at point & time of need, modules to analyze current physical, cognitive & health states and knowledge of Soldier health and physiological states. Near term (FY22-31) deliverables include: on-soldier monitor of select physiological measures- physical, cognitive, and health state monitoring; real-time sensing - select biomarkers; and, knowledge for decision support. Mid-term (FY29-37) deliverables include: individualized continuous near real-time state sensing enabled by SynBio sensors and data to inform decision aids. Far-term (FY32-40) deliverables include: comprehensive, integrated real-time physical, cog and health state sensing through SynBio sensors; and, predictable state informs decision tools.

The purpose of the **SHAPES Interventions** is to improve operational and training performance and recovery and provide whole body tailored Soldier sense and respond enhancements thru bio/genomic interventions. For example, the ‘Health Kit’ will provide solutions to improve health, illness recovery & trauma recovery (via synthetic biology, nutrition, and pharmaceuticals). Capabilities include accelerated trauma and wound stabilization and repair and threat detection, in vivo sense/response to pathogens, immune modulation, genomic modification, new vaccines, and psychological interventions (e.g., synthetic mucins for cognitive enhancement). Another example includes the ‘Physical Kit’, which will provide personalized probiotics & metabolic interventions and tailored genomic & bio engineering enhancements. Near term (FY22-31) deliverables include: optimize, enhance and sustain tools to improve operational & training performance & recovery; and, rapid response countermeasures. Mid-term (FY29-37) deliverables include: solutions to improve health, illness recovery & trauma recovery (synthetic bio, nutrition, pharmaceuticals); rapid performance resilience to improve physical performance; and, increase endurance, strength & task performance. Far-term (FY32-40) deliverables include: whole body tailored Soldier sense and respond enhancements thru bio/genomic interventions; control of biological functions impacting cog/psych perf (bio state engineering) In-situ fatigue and stress mitigation; and, genomic manipulation.

The purpose of the **SHAPES Decision Aid** is to provide integrated physiological Soldier Data Twin to monitor and predict health & performance states, automated sense and respond systems to improve performance and health using physiological digital twin technology, automatic bio manipulation as response to threats/stressors/illness in-situ, and fatigue/stress/illness mitigation though controlled SynBio toolkits & decision tools. Features include physiological health/trauma and physical/cognitive performance Data Twin

state model; performance and health prediction, optimization & readiness tool; analytic decision support tool for resilient Soldier performance and health; AI/ML Tools to drive timely interventions; bio/genomic decision tools; and, needed information provided with interventions (some automated). Near term (FY22-31) deliverables include: physical, cognitive, health state monitoring; and, interventions to improve state and task performance. Mid-term (FY29-37) deliverables include: neurological/cognitive state sensing; control of biological functions impacting physical performance; cognitive physiology prediction; optimization of cognitive performance; and, physiology prediction. Far-term (FY32-40) deliverables include: integrated real-time prediction of physical, cognitive and health state assessment; automated sense and respond systems; and, automatic bio manipulation using synthetic biology.

Figure 11 demonstrates the time maturation P&HSM component of the SHAPES kit. As time progresses from Phase 1 (FY22-31) to Phase 3 (FY32-40), there will be increasing understanding of integrative physiology and a progressive increase in Soldier performance.

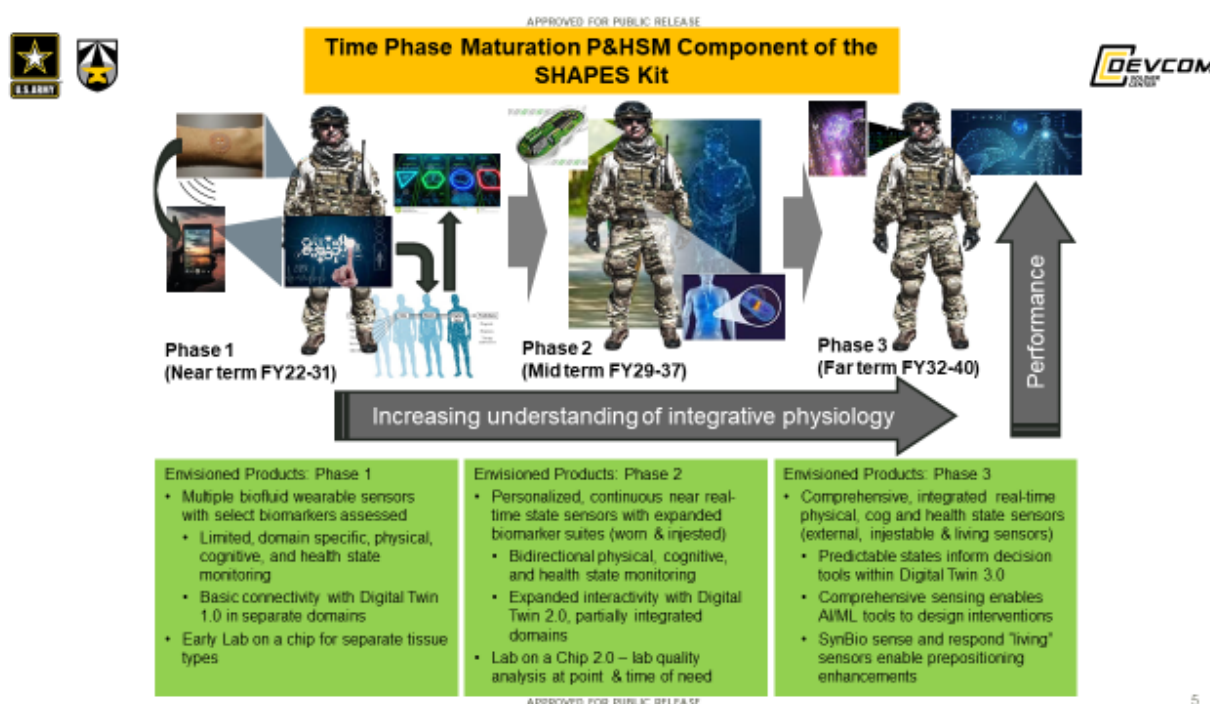


Figure 11. Time Phase Maturation of the SynBio HeAlth, Performance and Extended Survival (SHAPES) Kit

Panel discussion

As with prior LOE1-focused workshops, attendees continued to indicate that it was helpful to consider their research efforts in the context of the realistic situation presented in the vignette. Observations from the panel discussion regarding the vignette itself, and integration of the vignette into capability development, follow.

There were no additional observations from the vignette beyond what has been previously discussed (summarized herein and in Appendix C). Additional considerations to make the vignette more realistic or useful were discussed during this session and are presented below and summarized in Appendix C.

- Present multiple future-focused vignettes, addressing health and human performance, to the S&T community in order to comprehensively identify pain points and propose solutions

- This notion was discussed during various workshops as a means to more comprehensively identify human-level conditions, “pain points” and S&T solutions. This workshop series has discussed one historic vignette, which will be used during the MHP concept development process. Future LOE1-focused workshops present, review and discuss additional, future-focused, vignettes, to identify problems related to health and human performance and S&T solutions within the LOE1 space.
- Include both mission planning and operational elements in the vignette (e.g., perhaps a separate vignette that incorporates these elements).
- Consider including baseline state (how does the soldier come into the vignette ahead of time, e.g., dehydration, sleep status, etc...).
 - While this is a possibility in some scenarios, this baseline information will not always be available to leaders.
- Consider additional solutions that we working on in the S&T space that would benefit the protagonist in this vignette.
 - Challenges related to Soldier adaptation to extreme environments (extreme hot/cold, enclosed spaces, high altitudes) and physical demands (e.g., load carriage)
 - Fitness, hydration and nutrition management
 - Mindfulness
- Consider additional vignettes and vignettes with more future-focused elements.
 - A vignette targeting aviator state monitoring, to include more near-term targets, e.g., accessing data thru external sensors to give insight into aviator/operator states to feed into cockpit dashboard and feedback systems.
 - MHP concept development process is currently defining the future human-level environment and the capabilities required to succeed in that environment. During that process, the S&T community will review/apply additional vignettes to more comprehensively identify the S&T necessary to deliver the required capabilities. For example, future LOE1-focused workshops will present, review and discuss additional, future-focused, vignettes, to identify problems related to health and human performance and S&T solutions within the LOE1 space.

The panel discussion was helpful in adding perspective to the vignette and the protagonist’s situations. With regard to integrating the emerging capabilities presented today, within the vignette situation, a discussion ensued regarding biomarkers, where an attendee mentioned that each measure is just a snap shot in time, whereas physiology is dynamic emphasizing the importance to consult SMEs when discussing application of each of these biomarkers. For example, cortisol might be important, but how important is it in the context of other biomarkers and why it is important from a practical standpoint? With regard to acoustic sensing, the benefit of considering and exploiting both inward physiological sensing and external sensing was emphasized. Inward sensing includes respirator rate, rales, cough (e.g. to estimate pulmonary ventilation, anxiety, respiratory irritants/infections), heart sounds (e.g., to estimate work rate, heat strain/core temperature elevation) and cognitive state (e.g., speech-derived metrics of irritability and depression and group cohesion metrics). Outwards environmental sensing provides situational awareness. For example excessive noise levels to indicate when someone needs to don or activate hearing protection; gunshot detection (e.g., range, elevation, distance, type); and, vehicle/UAV detection. Additionally, temperature sensing RFID fibers minimize risk of peripheral cold injuries, manage work/rest and track sleep status. Further, given that there are

significant changes in body temperature in relation to sleep, for example, this technology could be used for sleep management. Lastly, there is application in combat casualty care.

In terms of biomarkers, it's important to identify what is important to measure and why it is important to measure. If a biomarker contributes to a Soldier "being in the red" (in terms of status monitoring), what is the significance of that observation? Thus, conversation ensued regarding MOPs and MOEs similar to previous workshops. The application of artificial intelligence and machine learning, in the context of applying biosensing capabilities will provide a way to better identify the impact on measures of performance. Indeed, this is the topic of discussion during the 10 JAN workshop discussed later herein.

In closing, an attendee indicated the importance of including these discussions in the context of tri-service working groups, given that some of these technologies are not unique to the Army and our Soldiers. For example, the Biotech COI (Optimizing Warfighter Performance sub-group) is a venue for these discussions.

Identifying emerging relationships, and novel approaches and analytical techniques to identify relationships, between human health, physiology/neurobiology, attributes, states and performance outcomes

January 10, 2022

This session was moderated by Dr. Tracey Smith (Lead, LOE1).

Novel data analyses approaches (Dr. Kathryn Taylor, USARIEM)

The definition of big data is a combination of structured, semi-structured and unstructured data produced on a large scale that can be evaluated to make statistical inferences. There is a large amount of data collected on Soldiers (administrative, medical, performance etc.). This is collected at the population level and it can be used to evaluate factors that impact human health, physiology, neurobiology and performance. Potential benefits include detecting diseases, injuries, performance decrements etc. at earlier stages, improving how they can be treated more easily and effectively and managing specific individual and population health outcomes. There is also a need to analyze real-time data collection (e.g. from wearables) produces an enormous amount of data. This is not collected at a population level and there is an ability to yield new insights into how physiologic factors impact health and performance.



The Five V's of Big Data



1. Volume
 - » Terabytes, petabytes or larger
2. Velocity
 - » Real-time vs extracted data
3. Variety
 - » Different data sources
 - » Different data types
4. Veracity
 - » Data quality or accuracy
5. Value
 - » Transforming data into something meaningful and useful



Kathryn Taylor, ScD, Research Epidemiologist, Kathryn.m.taylor41.civ@mail.mil

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Figure 12. The Five V's of Big Data

Dr. Taylor indicated key areas of concern when it comes to “big data” (Figure 12). In terms of volume and velocity, when accessing large and current data, data access is a problem to consider. This is a lengthy process (involving, for example, data collection, data aggregation, and data sharing agreements) and we may not know if data is what we need. Synthetic data is a potential solution, i.e., artificially generated data based on real world events, theory based in early work in data simulation. This type of data retains the structure or relationships of the original data but is not exactly the same; and, under proper protocols, should not be able to trace synthetic data back to the original data from which it was derived.

With regard to variety, making statistical inference from multiple data sources can pose problems with standardization of the data. Measurement methodology may vary between collection sites and tools used may be different, e.g., heart rate measurement. There is correlated error by collection site, e.g., random error is expected in data; and, combining data across sites with varying error could potentially induce systematic error. Another potential problem is standardizing data collected by multiple sources. A potential solution is model calibration (continuous variables) or matrix methods (binary/ categorical variables). Initially used as a statistical method for adjusting point and interval estimates of effects obtained from regression models; and, commonly used in epidemiology for bias due to measurement error (Spiegelman, 1997). This corrects for differences in measurements in separate models and pools estimates; and, requires validation studies to understand the relationships between different types of measurements. Multilevel modeling to account for unequal correlation between and within data sources is another potential solution. Similar to how multi-site studies are evaluated in statistical models; and, depending on data, a simple adjustment for site within a model may be sufficient

With regard to veracity: using data not collected for research, a potential problem is missing data. For example, incomplete data sets and loss to follow-up. In population level data this arises when we can no longer collect information on an individual so data is missing (e.g., after Military discharge). This can result in

selection bias (healthy warrior bias), e.g., healthier Soldiers remain in service longer. If two individuals have the same occupational exposure but we only capture outcome information on the healthy individuals, the negative effects of that exposure can be muted or appear protective. A potential solution to missing data is multiple imputation. This concept relies on replacing missing values with a value derived from the data and consists of imputing multiple times, obtaining distribution of newly imputed data, analyzing each imputed data set as if complete data were observed, and appropriately summarizing results across data sets. Within the pooling phase, you can account for the additional uncertainty (within the variance) due to the missing data. Another potential solution is inverse probability weighting (IPW). With this approach, the sample is re-weighted using known factors effecting loss to follow-up to create the best estimate of the unobserved full & complete data. IPW is used to create a pseudo-population that would have been observed had losses to follow up not occurred. Analyses are conducted in this pseudo population

Conclusions: using large datasets is an invaluable asset for identifying emerging relationships between human health, physiology/neurobiology, attributes, states and performance outcomes. The overall usefulness of the data will come down to how data issues are accounted for within the 5 V's (Volume, Velocity, Variety, Veracity, and Value). Analytics are a useful tool for overcoming some issues. Caveat: Analytics is not a fix to poor study design.

MASTR-E Population-Level Performance Modeling (PLPM) and Readiness Assessment and Model Predictions for Unit Performance (RAMP-UP) (Dr. Brunye, DEVCOM-SC)

The MASTR-E Population-Level Performance Modeling (PLPM) and Readiness Assessment and Model Predictions for Unit Performance (RAMP-UP) are efforts within the MASTR-E program, previously discussed in detail herein. Briefly, MASTR-E conducts lab and field research and test and evaluation events to develop & validate innovative tools (measures, algorithms) for interpreting wearable sensor data, predicting performance outcomes, and enhancing Soldier and small team performance (lethality, resilience, situational awareness and DM). The MASTR-E thrust areas particularly relevant for this topic include baselining Soldiers in physical, social, emotional and health domains, the evaluation of wearable biosensing devices, developing algorithms for performance prediction, and testing performance enhancement interventions.

The PLPM and RAMP-UP projects develop predictive models and software tools linking states and traits (X factors) to performance outcomes (Y) that are at the core of infantry functioning. This is a very challenging objective, conceptually and technically; and, there are multiple ways to approach this, each with strengths and weaknesses. This project takes a top-down approach, with population-level models (i.e., risk models, macro-level analysis with many predictors and many outcomes) predicting at the company level (versus individual level) while leveraging findings from a bottom-up approach (e.g., highly-trained models, micro-level analysis with few predictors and few outcomes) at the individual level.

A key characteristic of this effort is that it leverages prior efforts (academia, industry and DoD) assessing associations between traits and states and performance outcomes, from both the cognitive and physical perspective. The overall approach of this effort is to identify this extant meta-analyses and research by extracting, standardizing and tabulating coefficients and organizing features (e.g., stress, physical exertion, sleep status, hydration, etc...) and outputs (e.g., reaction time, executive function, memory, etc...). Thus far, this includes data from 183 meta-analyses with over 2 million participants. The effort then gathers data on X factors (i.e., traits and states) & Y outcomes (i.e., performance outcomes) to identify marginal distributions

(currently ~1.5 million data points and ~160K per XY marginal relationships). From that point, joint model fitting ensues using four primary analytic machine learning approaches, starting with copula approach, adaptive LASSO, optimal transport, and Gaussian mixture modeling (the latter of which, GMM, was ultimately chosen because it has the best efficiency at scale). The joint model fitting is followed by coding the algorithms, which allow us to predict performance outcomes (y) given states and traits (x). However, since the performance outputs may not be actionable in the field, the effort further maps the predicted outcomes (x's) to Warfighter outcomes, i.e., taking reaction time, memory, language processing, and other outcomes and relating them to threat detection, marksmanship, communications, etc... Further details on this modeling, to include building marginal and joint model fitting is described in Brunye et al, Toward Predicting Human Performance Outcomes from Wearable Technologies: A Computational Modeling Approach, *Frontiers in Physiology*, Sept 2021.

The models underlying the PLPM effort are demonstrated to stakeholders through the RAMP-UP software tool (Figure 13), which allows users at Soldier touch points to manipulate the model in an intuitive way and visualize the model outcomes. The tool provides status indicators (i.e., the X factors) and moving the slider affects the predicted outcomes, expressed as outcome distributions (to include confidence in the prediction, bottom Figure 13). Weighted combinations of the model outcomes inform tactical prediction (top right hand corner of Figure 13) and ultimately physical and cognitive readiness (middle of Figure 13).

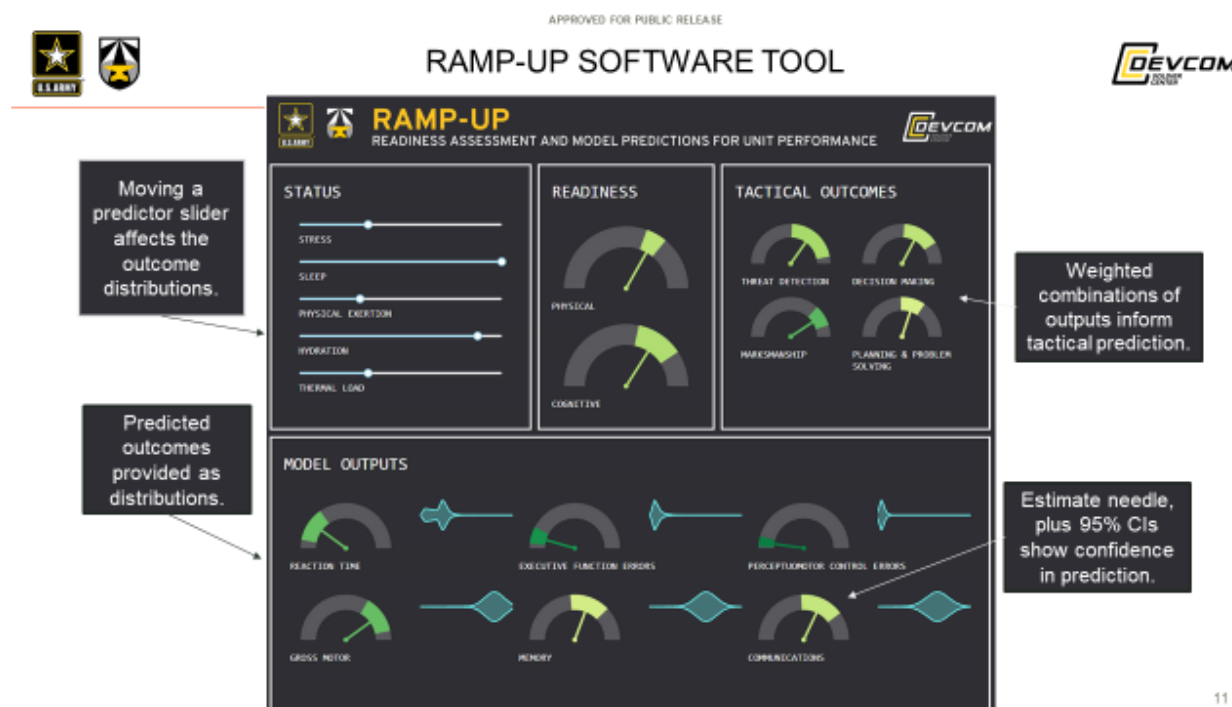


Figure 13. RAMP-UP Software Tool

This effort established performance benchmarks from FY21 to FY23. In terms of defining units and labeling Scales (FY21+), the team has completed the following two tasks: expanded X marginal inputs to suit user needs/measures, using probability-based approach; and, labeled scales in unit-specific manner to suit user needs/inputs. In terms of interaction terms & collinearity (FY21+), the team has demonstrated two X's and one

Y and will move forward to demonstrate five X's and one Y (twice: thermhot, thermcold), then repeated for each of 7 Y's (total of 14 models), and incorporate an understanding of multi-collinearity among X's (e.g., sleep/stress, exertion/stress). In terms of model expansion (FY22+), the team will focus on integrating time (pending for exertion, 4 bins, up to 56 models), MASTR-E database integration, incorporating additional X factors and outcomes based on unit needs & MASTR-E outcomes; and, integrating Soldier data from MASTR-E laboratory and field studies to better define marginal & joint distributions. In terms of model validation (FY23+), the team will focus on laboratory and simulation validation of model predictions and assess generalization of predictions to field contexts. In terms of integration (FY23+), the team will incorporate extant sub-models, and integrate models into mission outcome simulations and route planning tools. Finally, we will integrate and demonstrate the value of real-time inputs (e.g., Readiband, Garmin Fenix 6, Polar Grit X, Lifelens, and/or Oura) to the model, and explore real-time predictive capability.

Panel discussion

As with prior LOE1-focused workshops, attendees continued to indicate that it was helpful to consider their research efforts in the context of the realistic situation presented in the vignette. Observations from the panel discussion regarding the vignette itself, and integration of the vignette into capability development, follow.

There were no additional observations from the vignette, nor additional considerations to make the vignette more realistic or useful, beyond what has been previously discussed (i.e., summarized herein and in Appendix C).

The panel discussion was helpful in adding perspective to the vignette and the protagonist's situations. In terms of integrating the emerging capabilities presented during the workshop, within the context of the vignette, a discussion ensued with regard to status tracking. The PLPM has continuous output, with no discrete categories assigned. E.g., when someone is red, it is difficult to determine what that really means in terms of performance outcomes. For example, given a mission set that involves manning a road block versus entering and clearing a building, both have very different physical demands. As such, the status monitor may indicate "in the red" for a performance outcome that may be important for predicting one mission outcome, but not the other. Thus, as we develop a suite of wearables with a set of algorithms that can indicate predicted cognitive and physical outcomes, it's critically important to consider how these data will translate to operational outcomes. Soldiers will be stressed, tired, physically encumbered, etc...therefore, thus status monitoring data is truly useful when it becomes actionable by the Commander for modifying mission plans. As such, PLPM is pulling in groups of operational leaders (e.g., commanders) for feedback on the tool and how to get at the operational relevance of the data. The vignette drives the importance of further adjustments to the software tool and modeling to meet the needs of leadership, e.g., expanding the list of tactical outcomes that the model can predict, providing more detail in the status indicators, and making the software tailorable across different echelons in many different operational contexts. While red, amber and green status indicators may be adequate in some situation, other scenarios will require additional details linking it to operational tasks (i.e., measures of effectiveness). Additional discussion ensued regard how these models contribute to defining measures of performance and measures of effectiveness in the context of MHP's concept development process. The concept development process is identifying factors that are different and unique in the FOE, and the related performance metrics. The modeling approach can lend insight into how we measure that performance and the operational outcome achieved by that performance, to include how variations in that particular performance impact that operational outcome. As such, as the MHP community continues to identify future performance throughout the concept development process, these models can contribute to

determine these critical measures of operational effectiveness (via determining the linkages between tactical outcomes and operational effectiveness).

There was also discussion regarding integration of additional S&T SMEs into the concept development process. This would be useful for identifying and understanding additional tactical outcomes that ultimately can be integrated into the PLMP model (and that the model can predict); and, to engage in discussions regarding the associations between tactical outcomes and operational outcomes (i.e., measures of effectiveness).

Developing/validating methods to assess cognitive performance and mitigate effects of cognitive load

January 24, 2022

This session was moderated by Dr. Tracey Smith (Lead, LOE1).

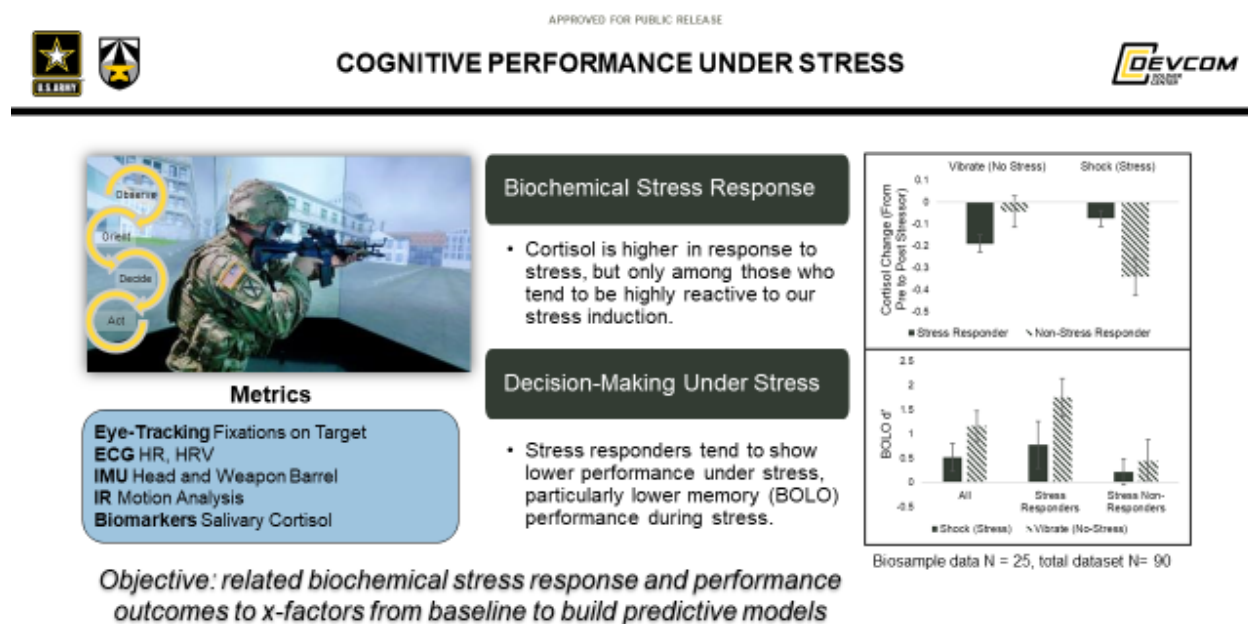
Mitigating cognitive performance decrements in dismounted Soldiers (Drs. Grace Giles and Aaron Gardonay, DEVCOM-SC)

The DEVCOM SC Cognitive Science and Applications Team's (CSAT) mission is to optimize Soldier and small unit perception, cognition, and interaction through innovative science and technology through a combination of 6.1, 6.2 and 6.3 funding. Specific to mitigating cognitive performance decrements, the team seeks to measure and understand the conditions that affect cognitive performance. That is, in order to optimize cognitive performance to mitigate effects of increasing mental demands, high stress for extended periods of time, it is important to understand conditions that affect cognitive performance and specific cognitive processes impacted to identify how best to intervene (e.g., determine what needs to be optimized and under what conditions). The next step of this approach to mitigate cognitive performance decrements is to predict performance outcomes to inform techniques for optimization. For example, identify the indicators that optimization techniques need to be applied, identify how predictive models may be used to drive optimization methods; and, identify how predictive models may be used to optimize/enhance performance (model as the optimizer). Lastly, this approach seeks to optimize performance through technology. For example, determine how information may be portrayed to dismounted Soldiers in a way that reduces cognitive burden and distraction; determine the efficacy of non-invasive brain stimulation techniques to mitigate effects of stress or to enhance learning; and, determine how best practices in learning science may be applied to make knowledge/skills robust and adaptable under conditions of stress. The application of this framework allows for understanding performance potential and performance limits of individuals and teams; predicting adverse performance outcomes before they arise and adversely affect the mission; and, identifying selection, training, and operational strategies to mitigate adverse outcomes and help sustain performance under stress and adversity.

In terms of predicting impacts of cognitive and physical stress on performance, challenges exist. For example, cognitive and physical stressors carry diverse and often unpredictable influences on human performance, including the ability to regulate emotions, retrieve memories, think and behave flexibly and adaptively, and maintain the decisive edge. However, the Army lacks validated methods for eliciting mental and physical stress and measuring their influence on Soldier-relevant performance outcomes, and data and models to predict how individual-level attributes alter this relationship. One solution to this challenge includes a comprehensive

immersive scenario to isolate and elicit cognitive and physical stress, engage Soldiers in threat detection, marksmanship, and decision-making tasks, and measure multi-modal data outcomes, which has been developed and validated by CSAT. This technology is accompanied by a machine learning framework to process, structure, and interpret data. The approach to integrating this technology is to work with experts in immersive simulation and infantry SMEs to develop scenarios to induce stress and quantify performance outcomes; and, to conduct a series of large-scale experiments with human subjects to characterize physiological and biochemical stress responses and link them to Soldier-relevant performance outcomes. The data from this work feeds predictive modeling (PLPM, presented at the 10 Jan workshop), algorithm development, and software tools (RAMP-UP) in MASTRE program (data collection ongoing). Ultimately, results will quantify the impacts of stress on cognition (decision-making, memory, spatial orienting).

Figure 14 demonstrates recent preliminary data in biochemical stress response and performance outcomes to build predictive models. Data indicates that some Soldiers are sensitive to stress on a biochemical level, as evidence by heightened cortisol levels during the stressor (technically less decline throughout the morning), whereas others are not. This dichotomy is used to assess measures of performance, and see that stress responders tend to show lower performance under stress, for instance in memory for objects from a BOLO list. These findings are based on a subset of the entire sample, which is forthcoming to determine how stress responders and non-responders perform throughout the scenario.



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Figure 14. Cognitive Performance under Stress: Predictive Modeling

One potential optimization strategy to increase cognitive capacity and resilience to stress is neurostimulation. A current challenge is that reliable and robust methods (tools, techniques) are needed for increasing cognitive capacity and resilience to stress. For example, models and software tools are needed to predict how Soldiers might respond to various neurostimulation techniques; and, the current approach is mixed human subjects experimentation and predictive modeling. There are multiple types of neurostimulation including Cranial Electrotherapy Stimulation (or CES) and Transcranial Direct Current Stimulation (or tDCS). Current

experimentation aims to assess whether CES decreases stress responses and enhanced visual search, target detection, threat classification, decision making, and marksmanship under stress. Other experiments determine whether tCDS increases the ability to balance simultaneous demands of cognitive and physical tasks and accelerate procedural skill acquisition. CSAT has also developed a meta-analytic model and software tool to manipulate model inputs and visualize model outputs, and detail optimal parameter combinations. Some emerging results in this area show that Active versus Sham CES decreases Cortisol responses to stress, but only among those who tend to be highly reactive to our stress induction. Stress responders tend to show lower performance overall, and there's a trend that CES can help improve their BOLO performance and navigation decisions under stress. This is evidence of how "measuring to understand" (discussed herein) transitions to optimization strategies. Future analyses will delve into further characterizing stress responders and non-responders.

Another effort in mitigating cognitive performance decrements in dismounted Soldiers centers on maximally-effective level of detail experimentation (MELOD-E). This work is driven by the ongoing One World Terrain (OWT) effort within the Synthetic Training Environment Cross Functional Team (STE-CFT). While photogrammetry-derived 3D terrain datasets offer transformative capabilities for Soldier training and operations they are large and require significant compute/power/bandwidth to process, visualize, and transmit. Further, network bottlenecks can delay or prevent delivery of 3D terrains to the point of need, degrading training effectiveness and operational readiness. CSAT is seeking solutions by conducting experiments with human subjects to determine optimal graphical level of detail (LOD) for different terrain types and different Soldier use cases. The team is developing solutions by conducting large-scale laboratory experiments examining how varied LOD impacts Soldier performance in synthetic terrain reasoning tasks and across varied terrains; and, establishing maximally-effective LODs for specific 3D terrain dataset use cases based on quantitative performance data. Data collection is ongoing and preliminary knowledge products continually transitioned to STE-CFT via OWT (Gardony et al, 2021). There was inquiry from the audience regarding the level of detail and ability to perform a specific task, e.g., is the solution generalizable to other tasks demands and mission sets or does it vary widely, regardless of mission demands. In terms of general principles, the answer is "yes" (e.g., in natural environments, discrete level of detail may not be necessary); however, in urban environments additional detail is required. Work is starting in collaboration with OWT to test automated LOD in order to algorithmically classify and selectively decimate structures within the environment, i.e., classify building vs. roads vs. trees and modify their LOD individually.

Another transformative emerging technology area for the dismounted Soldier is augmented reality (AR). The modern multi-domain battlefield will present infantry with significant quantities of complex and rapidly changing information – more than ever before. Head-mounted AR systems, such as those under development by the IVAS and IMHS programs, are being developed, in part, to address this challenge by providing hands-free, heads-up contextual information that can: (1) Improve situational awareness (SA), (2) Minimize cognitive load, (3) and enhance lethality. However, developing user interactions that minimize cognitive burden and maximize usability and user acceptance is challenging. Experiments with human subjects are ongoing to evaluate how novel multimodal interaction techniques impact human performance and user experience in AR. This approach centers on working with experts in immersive simulation, academic, and industry partners to develop and evaluate novel AR interaction techniques that leverage emerging gaze and gesture sensing technologies and algorithms; and, conducting a series of large-scale human subjects laboratory experiments to collect quantitative performance metrics and user experience data in order to characterize cognitive impact and usability of novel interfaces. Data collection is ongoing, with preliminary knowledge products continually

transitioned to PEO-S/PM-IVAS, to include technical reports, briefings, and software prototypes. Some discussion among the group ensued regarding IVAS, specifically whether use of the hololens has been maximized for mission command and control decisions under stress. The current work presented herein focuses on individual soldiers and there's interest, and ongoing work from other groups, such as DEVCOM SC – STTC (ARES) and DEVCOM ARL – HRED (AURORA XR COP), in taking this a step further using IVAS (hololens) for multi-user mission command and control (commander level and up) decision making (e.g., to get common operational picture) to speed up the OODA (Observe Orient Decide Act) loop.

Application of learning science to Army skill and knowledge acquisition is another area of focus. This effort involves interfacing directly with Army schoolhouses to apply psychological research, learning science best practices, and emerging supplementary online and mobile learning tools and technologies to optimize schoolhouse learning and retention. Passing and maintaining Soldier knowledge and skill certifications today remains a readiness bottleneck. Improving pass rates at Army schoolhouses today provides immediate and recognizable benefit for force readiness tomorrow. Given the annual throughput of Soldiers through popular courses, like the Sabaluaski Air Assault School's Air Assault course, this amounts to several thousand Soldiers per year and improving pass rates by even a few percentage points can have big impacts on force readiness. The Applied Learning Science for Skill and Knowledge Acquisition (ALSSKA) effort consists of close collaboration with TSAAS instructors and the Advanced Distributed Learning Initiative using their Pervasive Learning System to develop a supplementary mobile and web application incorporating science of learning best practices to optimize outside-the-classroom study. Data collection was recently completed with over 400 Soldiers across four classes of the Air Assault Course and data analyses is ongoing to determine how application use impacted course exams and skill assessments. If successful, ALSSKA will demonstrate that supplementary learning tools can significantly improve learning outcomes for schoolhouses; require minimal investment of schoolhouse resources; and, lay a foundation for future research efforts to enhance schoolhouse learning. Lessons learned from this effort will be communicated and transitioned to schoolhouse leadership and other relevant organizations in the Army enterprise. There was some discussion regarding whether or not this research in its current state can tease out the "best practices" that were integrated to determine what methods are actually working and which aren't. However, it is evident that this research will lay a field-validated platform for further exploration of this important question.

Mitigating effect of cognitive load in aviators (Dr. Paul St. Onge, USAARL)

Current methods of mitigating the effect of cognitive load in aviators include checklists (i.e., used for preflight planning through all phases of flight and including the after action report); kneeboard information (e.g., manuals and procedures); teaming (e.g., two pilots per aircraft, crew, other aircraft crew & air traffic control); specific information presented based on phase of flight (e.g., enroute pages versus hover pages). Current S&T efforts support future scalable information and autonomy based on mission phase and biometric measured cognitive workload.

By way of background, there are a limited number of aircraft available in the Army. The main aircraft is the UH-60 Blackhawk, which meets a majority of the Army mission profile needs. For larger or heavier loads, there is the CH-47 Chinook, which can transport 200 Soldiers. The AH-64 Apache is a helicopter with exchangeable fuel cells to increase its range beyond that of the other aircraft and is outfitted with rockets on each side and a gun system that uses a head-tracking aiming system. The UH-72 Lakota is a relatively newly acquired training helicopter used for initial Army flight training. The Army also has unmanned aircraft platforms that are typically

used for loitering missions (e.g., to monitor a target and relay information back to headquarters). In addition to the MH-60 Blackhawk and MH-47 Chinook, Special Forces group routinely flies the MH-6 Little Bird, which provides an efficient means to deliver a small number of troops (up to ~4) to difficult locations.

Figure 15 demonstrates various Army helicopter flight decks with different configurations. The left middle and left bottom photo shows a Blackhawk flight deck, which is particularly relevant for this session given that USAARL has reproduced this as a full motion simulator (top left photo) for research purposes, complete with a control room allowing the mimicking of command and control capabilities. Of the 6 smaller pictures, the top right and top middle are images of the CH-47 flight deck and the bottom left is the ground station operator station for the Army's unmanned platforms. The top right is a photo of the one of the riskiest activities in Army aviation, dual aircraft midair refueling. The bottom right is a photo of the flight deck of the refueling aircraft.

These photos demonstrate that all flight decks and duties are conducted by teams and the teams are trained to address specific cognitively demanding tasks in parallel to achieve each specific mission set. Of note, pilots are not interchangeable with different aircraft. They are trained to be fully proficient in all aspects of flight in their specific airframe. However, they still have the skills to perform basic tasks with any aircraft.



Figure 15. DVIDS photos demonstrating different helicopter cockpit set-ups

Checklists serve a number of purposes for mitigating cognitive load. For example, they aid pilots in recalling the process of configuring the aircraft, provide a standard foundation for verifying aircraft configuration, provide convenient sequences for motor movements and eye fixations along flight deck panels, provide sequential framework to meet internal and external flight deck operational requirements, allow mutual supervision among crew members, keep all crew members informed, dictate the duties of each crew member to optimize crew coordination, and serve as a quality control tool by flight management and government regulators. Examples of checklists include before exterior check, exterior check, before starting engines, starting engines, before taxi, hover check, before and after takeoff, before and after landing, parking and shut down, before leaving helicopter, and after action paperwork. These checklists are used either as a paper publication or on an iPad/application. Typically, an aviator walks through the checklist item by item using their

finger. However, if the pilot is distracted by any one of the multiple things occurring during whichever phase of flight they are in, it is possible for a checklist item to be overlooked. Scientists are working to lessen, or eliminate, that risk.

One of the most important checklists provide aviators with guidance of what to do in an emergency. For example, flight reference cards and knee boards are additional tools for optimizing aviator performance and include the execution of emergency procedures. The execution of emergency procedures is accomplished by using the Fly the aircraft, Alert the crew, Diagnose the emergency, Execute the emergency procedure, Communicate, Fly the aircraft (FADECF) methodology, which is a predetermined set of steps to take during an emergency,. Although “Flying” is the first and last step in the sequence to remind the pilots it is important to that one pilot must stay on the controls while the other focuses on the diagnoses and solution throughout the entire emergency. The FADECF contents improves response to emergencies by decreasing the amount of information pilots have to memorize. The U.S. Army flight reference cards are based on those developed by the UK and used by the commercial aviation industry.

Knee boards, or Electronic Flight Bag (EFB; usually an Apple iPad), typically attach to an aviator’s upper thigh and contains an Air Assault Mission Packet with crew and communications card, mission timeline, time-distance-heading route planning card, information about what the landing/pick (LZ/PZ), zones look like Inadvertent Instrument Meteorological Conditions (IIMC) plan, Forward Arming and Refueling Points (FARP) diagram card, execution checklist, and evasion plan of action (e.g., when taking fire from an enemy). DOD Flight Information Publications can be stored on the EFB and can include instrument approach procedures, charts for both visual flight rules (VFR) and instrument flight rules (IFR), and a flight information handbook.

In addition to the use of knee boards and checklists, Army aviation relies on teaming. All Army helicopters require 2 pilots. For example, Apache are tandem seating and neither pilot can see what the other is doing. This necessitates continuous conversation, which makes some parts of their job more difficult (e.g., one cannot simply point to a target or gesture to something in the cockpit). Alternatively, other helicopters are side-by-side seating enabling a combination of verbal and gesture communication. Pilots distribute the workload between them, with the controls, the radios, and the navigation all necessary tasks requiring attention simultaneously. This is not to mention sometimes needing to actually look out the window. Some aircraft require additional crew, e.g., the Chinook needs someone in the back to ensure the rotor system does not hit anything since it is not within view from the flight deck. Army Aviation also requires additional support on the ground, e.g., Air Traffic Control aids by decluttering the airspace when visibility is low. In order to reduce workload, standard regular cross-checks are conducted and there is a standard method for presenting information e.g., weather information, radio calls, and known terminology using aviation lexicon.

Conversations with pilots revealed their recommendations to reduce cognitive workload. These included: improvements in the layout of, and reduced reliance of pilots to complete, the checklists (e.g., artificial intelligence in the aircraft that can confirm all items on checklists have been completed); new cockpits should allow pilots to manipulate the instrument panel to match their preferences (e.g., ability to move instruments in the cockpit like application icons on a smart phone to increase efficiency); aircraft equipped with the technology to override pilot inputs that may compromise the safety of the crew (i.e., similar to what is available on commercial aircraft); improvements in color coding for warning, caution, and advisory lights in the cockpit; and finally the use of flight reference cards, which reduces the amount of information pilots typically would try to memorize.

Current S&T efforts support future scalable information and autonomy, based on mission phase and biometric measured cognitive workload. There is technology needed to adequately address future vertical lift (FVL) requirements, to include: managing cognitive workload to prevent overload, detecting cognitive workload in biometric signals, and integrating crew biometrics into flight systems to measure workload and health in real-time. This technology will enable safe/unsafe biometric thresholds to determine when intervention is needed to protect aircrew and enable scalable autonomy and also enables post- and future- mission planning.

Near-term research to achieve operator state monitoring goals and objectives in support of FVL requirements (Figure 16) will allow for enabled technology in the aircraft, i.e., provide the ports to get the information into the aircraft. Mid-term efforts (2035+) will bring this technology into the aircraft with scalable autonomy.

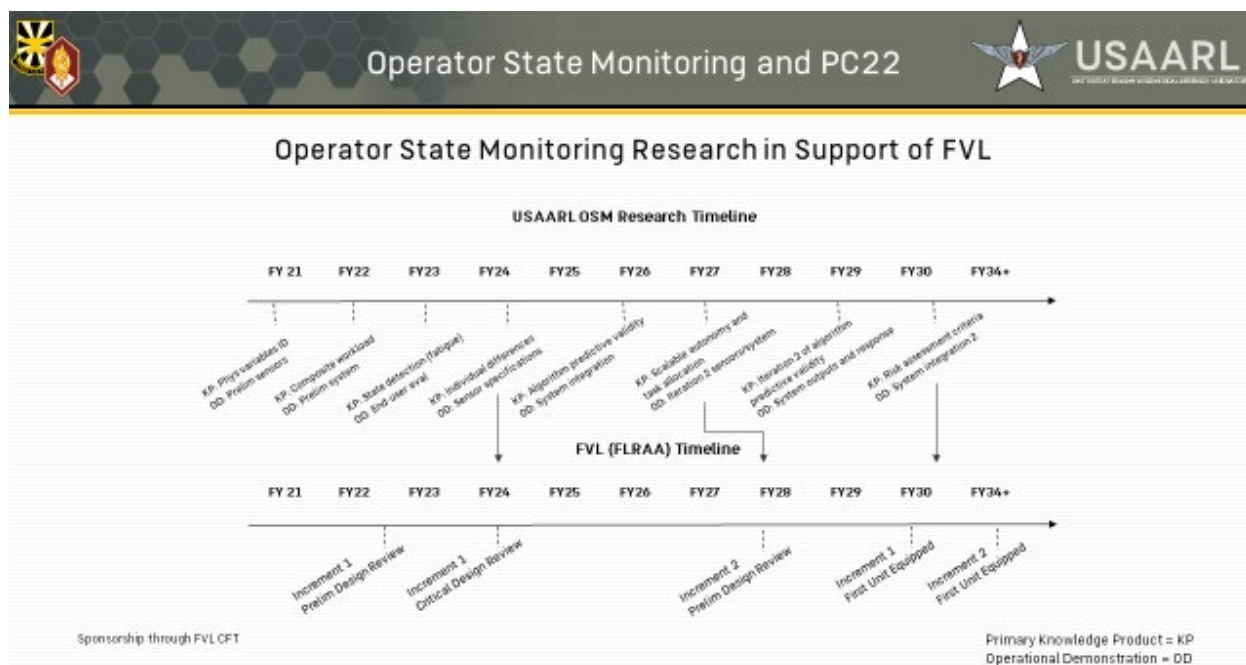


Figure 16. Operator state monitoring research in support of future vertical lift

These efforts are also synchronizing with Project Convergence 2022, wherein the objective is to demonstrate application of operator state monitoring sensors (e.g., heart rate variability, body temperature, blood pressure) from the aircraft cockpit that can broadcast on tactical networks, thus monitoring pilots in real-time (e.g., alertness, stress and workload) to inform the chain of command. Establishing this capability will allow the development of algorithms to contribute to the scalability and autonomy for health and performance of aviators.

With regard to mitigating cognitive decline in aviators, there was discussion regarding the relationship between performance indicators and aviator-specific tasks (e.g., characterization of successful performance), and flexibility of the system to be tailored depending on different scenarios. The mission profile, as well as the status of the individual, must be considered (e.g., low flying is very high intensity) when determining threshold parameters (e.g., when someone is “in the red”). Validity and reliability for predictors of performance is also

important, e.g., considering a set of parameters that may be adjusted when the pilot recognizes when there is a change in workload. Additionally, considerations are necessary regarding relationships with single-performance outcomes (e.g., if task is to hover) and metrics that are worth pursuing due to a reasonable degree of accuracy in a model. Additionally, while current efforts are working to put together a system that demonstrates validity, scientists also plan to conduct a reliability assessment as part of task analyses and tool design.

Panel discussion

As with prior LOE1-focused workshops, attendees continued to indicate that it was helpful to consider their research efforts in the context of the realistic situation presented in the vignette. Observations from the panel discussion regarding the vignette itself, and integration of the vignette into capability development, follow.

In terms of additional observations from the vignette, beyond what was previously discussed (herein and summarized in Appendix C), attendees noted that there is also a potential for caffeine withdrawal which may compromise cognitive capabilities. For example, the vignette mentioned rejection of cold coffee, and it's possible that the Soldiers are not consuming the amount of caffeine that they normally consume with may lead to caffeine withdrawal symptoms and subsequent cognitive performance impairment. There were no additional considerations to make the vignette more realistic or useful, beyond what has been previously discussed (i.e., summarized herein and in Appendix C).

Discussion ensued regarding the capabilities mentioned and practical application within the vignette. With regard to sleep, there's a lack of clarity as to how the person is feeling and the degree of cognitive decline due to sleep restriction/deprivation. The work that was discussed today, and the resulting models that were discussed during the prior workshop (e.g., PLPM, POC: Dr. Tad Brunye), can detect the cognitive decline related to sleep restriction, for example. Further, current work is addressing the development of sophisticated models to monitor and predict cognitive performance, but also how to render that information and deliver to military decision-makers in a useful manner for actionable decisions. In general, current models are predicting easily quantified outcomes that tend to be representative of the scientific research that already exists (i.e., highly measurable and reasonably validated). Each of these measures also apply to a variety of tasks and are then aggregated and translated into tactical performance outcomes that commanders actually care about (e.g., threat detection, mission planning, marksmanship, etc...). These measures and models can also make more general, composite, inferences (e.g., readiness).

The point was made that we have a lot of great ways of measuring performance using biosensors, in that we can reliably classify state from multi-modal sensor suits and there are emergent predictive models of performance and methods for optimizing performance. By and large, developing of many of these technologies is happening independently of one another (i.e., there are a number of folks that are doing this work from many different angles). Future discussions are necessary to bring these methods together, considering targets within the vignette, i.e., who, what, when, how these systems will come together for performance optimization.

An example from aviation for how this integration can occur involves reports from pilots who caught themselves falling asleep at the controls. This practice is acceptable if the other pilot knows that this is

happening. Thus, the aircraft would look at the current mission profile and future mission profile and determine whether a quick nap is allowed/acceptable; thus can alert pilots when someone falls asleep and wakes up. This could be the same for the ground vehicle (e.g., can take a quick nap, as long as there's an alert system to let others know when someone goes to sleep and wakes up).

Additionally, it was reiterated that knowledge gain from modeling efforts is important in and of itself. For example, there are a number of cognitive and physical symptoms (or decrements) in the vignette that are presented; and, understanding the source of these symptoms (or decrements) thru modeling can provide education and training tools to Soldiers. Soldiers can then recognize and triage it in the field based on that information (e.g., knowledge is power). We already do this in some areas (e.g., there are a number of programs in existence to educate and train soldiers on getting the proper amount of sleep or strategies when you can't get enough sleep); however, actually tying this education to modeling is lacking. Validating models offer a tool to "show not tell" Soldiers what human performance components are critical for their success in training and operations.

In summary, questions to consider for future workshops:

- 1) Determine targets within the vignette for these types of closed loop systems that are likely to be embedded with dismounted operations in the future.
- 2) If we could sense and classify performance in the vignette, what would we sense and classify?
- 3) If we could predict outcomes, what would we want to specifically predict?
- 4) If we could take one of the optimization strategies that we've discussed in the workshops (or another that we haven't touched on yet), where would we embed the technology in the vignette and what would we expect to happen?
- 5) How could all of these systems talk to each other and inform each other adaptively to overcome the challenges in the vignette?

Innovative solutions to optimize and enhance cognitive capabilities and socio-emotional status

February 7, 2022

This session was moderated by Dr. Tracey Smith (Lead, LOE1).

Psychological Readiness in 2035+: Resilience Strategies (Dr. Amy Adler)

Themes for this series of presentations included resilience building at the individual, team and leader level; assessment methods; and, field-based interventions to promote mental readiness in Warfighters. Research in this area focuses on individuals, teams and leaders and has relevance to Warfighters both now and in FOE team research and leadership.

This research effort is also the first to systematically characterize acute stress reaction in combat. An acute stress reaction in combat reflects a shifting set of physiological, emotional, and cognitive symptoms in response to a traumatic event. These reactions impact the individual's ability to function. In the case of combat, such a reaction, while not a diagnosable condition and understandable given the circumstances, can mean the individual, team and mission are endangered. In addressing this topic, the WRAIR team has found that 17% of Soldiers (or 1 in 6) with combat deployment experience reported possibly being so mentally

stressed during a combat-related event that they were unable to function for a period of time (Adler & Gutierrez, 2022a). The duration of this impairment is provided in Figure 17. While 23.6x% reported experiencing acute stress that lasted for less than 5 seconds, more than half reported acute stress that lasted longer than 5 minutes, and some (12%) reported acute stress that lasted for 3 days or longer. Symptoms of acute stress that last longer than three days may be diagnosable as an acute stress disorder. The research group has also published estimates of how many unit members have witnessed acute stress reactions in team members during combat (Adler, Svetlitzky & Gutierrez, 2020). Estimates suggest that 40-50% of Soldiers have witnessed these reactions during combat.

Such findings provide the foundation for developing team-based solutions to counter acute stress. Furthermore, it is also clear that solutions are needed to build resilience at the individual, team and leader level in order to support healthy adaptation to stress.

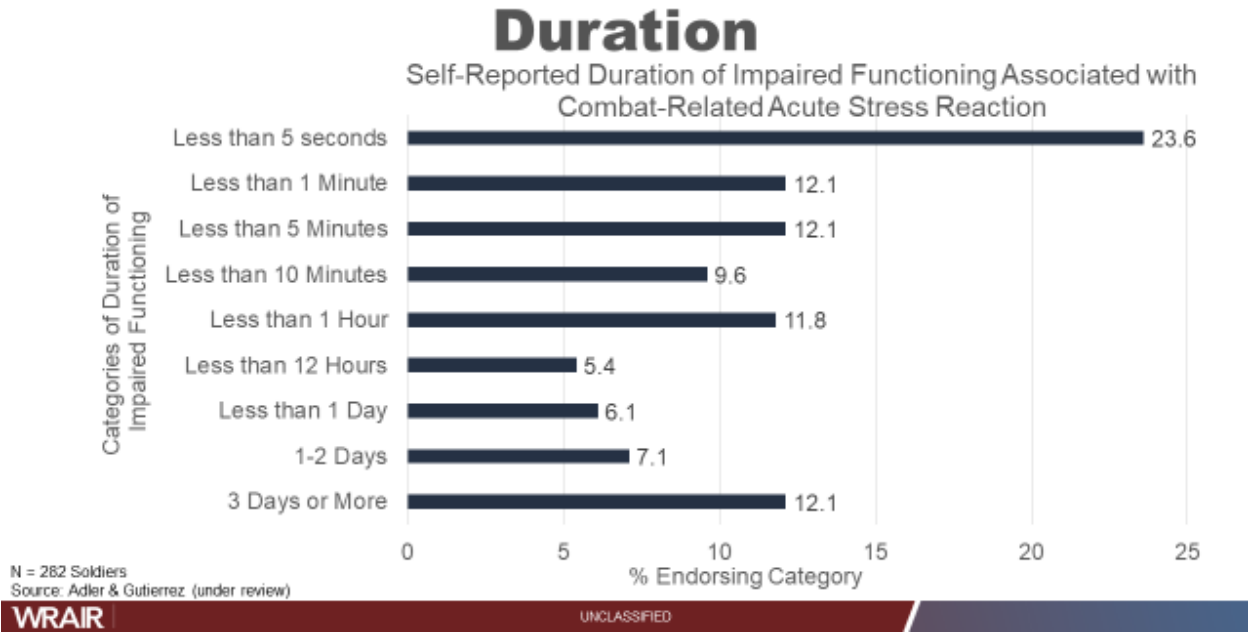


Figure 17. Percentage of individuals that self-reported impaired functioning associated with combat-related acute stress reaction

One effort, based on a collaboration with the Israel Defense Forces, is working to mitigate impaired functioning associated with acute stress. This intervention (iCOVER) consists of six steps that take less than 60 seconds to implement when a team member witnesses a fellow Soldier experiencing impaired functioning consequent to stress. The six steps are: Identify a buddy in need, Connect, Offer commitment, Verify facts, Establish order of events and Request action. Scientists have built a knowledge base showing that Soldiers find this tool relevant and useful both during realistic training and prior to deploying to combat, and this training fills a gap not previously addressed (e.g., Adler & Gutierrez, 2022b). Other military services, both in the U.S. and abroad have adapted and/or implemented this tool as well and troops in Ukraine have also adapted this intervention for their own use. The fact that Ukrainian counterparts have adapted this material demonstrates its ecological validity and immediate utility.

Other resilience-focused efforts are targeting mindfulness, defined as awareness of the present moment without elaboration or judgement. Mindfulness training has the potential to prevent impaired functioning under stress. For example, mindfulness-based attention training (MBAT), developed by Amishi Jha at the University of Miami, has been tested extensively in lab settings and also applied to Army operational units. MBAT is a relatively short-form of mindfulness training (it can be taught in an 8-hour course of 2 hours per week for 4 weeks) compared to other validated mindfulness training programs. Unlike these other programs which require years to develop trainers, MBAT trainers can be certified to deliver MBAT within 10 weeks, a relatively efficient training pipeline. To-date, WRAIR has conducted two primary projects using MBAT.

In small WRAIR studies with different types of operational units, mindfulness training resulted in performance improvements during operational tasks (e.g., marksmanship) while under stress; and, scores increased with frequency of practice (Nassif et al., 2021).

In another study, the Commanding General of the Army's Training and Doctrine Command (TRADOC) asked WRAIR to test mindfulness and yoga during basic combat training. In this large-scale group randomized trials, intervention platoons received the 8 hour MBAT course and 15 minutes of MBAT practice per day, coupled with 30 minutes of yoga per day (as part of the standard 15-min warm up and cool down for morning PT).. Data collection was completed in December of 2021, and results have been back-briefed to senior Army leadership. These data indicate that Soldiers receiving the mindfulness and yoga intervention demonstrated improvements in outcomes related to physical health, psychological health, use of mental skills and team cohesion, compared to Soldiers receiving training as usual. These effects were even stronger for those who implemented embedded practices during the duty day at least three times a week. These results demonstrate the impact that these interventions can have even when drill sergeants are skeptical, the feasibility of implementation, the interest of senior leaders in pursuing these approaches, and the potential for cultural shifts in integrating these approaches across the Army.

There was a follow-on discussion regarding integration of yoga. In addition to the work presented today, there is an ongoing, small randomized trial with senior leaders, integrating mindfulness and its impact on decision-making.

Loneliness is another component that negatively impacts resilience, particularly at the team level. Loneliness is common, (i.e., WRAIR research finds 1 in 3 Soldiers report loneliness). It is also associated with depression, alcohol and substance abuse, relationship difficulties, suicide-related behaviors, physical health problems, and higher incidence of mortality. The WRAIR has developed TeamCORE (cohesion and organizational readiness enhancement), a short training program that works to fortify team cohesion. There have been multiple studies focused on improving cohesion and reducing isolation. Most recently, WRAIR conducted a quasi-randomized trial that was completed Dec 2021 at Ft. Hood. Building on results from a pilot in 2019, WRAIR developed a leader module to focus on TeamCORE leadership behaviors. Collectively, this training program provides simple ways for teams and leaders to promote cohesion and to build group resilience to combat stress.

Efforts are also addressing specific behaviors that leaders can engage in to promote the behavioral health of their unit members. This approach focuses on domain-specific leadership (rather than general leadership skills) in order to target specific behaviors that support unit member mental health and well-being (Adler et al., 2014). One example of this domain-specific approach is the WRAIR's development of Sleep Leadership training. Sleep leadership training entails educating platoon leadership teams in sleep hygiene and how to apply these techniques in operational units. Results from a randomized trial found that Soldiers in the Sleep Leadership training condition reported more adequate sleep than Soldiers in the control condition. Studies

also find that sleep leadership impacts unit resilience following combat (Gunia et al., 2021). This leadership approach has also been adapted for COVID-19, resulting in the identification of specific leader behaviors associated with improved adherence to public health guidelines and less mental health symptoms associated with depression and anxiety. This research was conducted under the auspices of the Behavioral Health Advisory Team, and resulted in the development and dissemination of a Leaders Guide during COVID-19. This focuses on leaders targeting specific behaviors (domain-specific approaches) can be applied in a variety of contexts and demystifies the kinds of behaviors associated with improved unit resilience and readiness.

Psychological Readiness in the Future Operational Environment (2035+): Training and Evaluation Strategies (MAJ Carl Smith)

The goal of ongoing and future efforts in this area are focusing on preparing our Soldiers for the unique threats and stressors of FOE 2035+. Soldiers in the future operational will be under a great deal of stress and will not have some of the advantages of the current operational environment (e.g., information air superiority, communications electronic dominance and related factors). Executing mission command at all echelons, all the way down to the squad level, will be paramount in the FOE. Successfully executing mission command requires optimizing unit climate and culture; and, developing and implementing strategies to foster acquisition of leadership skills, moving away from classroom style learning, is a key component.

This session reviews the “Squad Leader Development Course”, getting at the heart of mission command, empowering small teams to move decisively; People First Task Force Cohesion Assessment Teams to foster optimal readiness through healthy unit culture; and, efforts embedding performance experts to develop training and evaluation strategies.

The Squad Leader Development Course (SLDC) was developed in response to Sergeant Major of the Army Grinston’s request to develop squad leaders that could effectively lead cohesive squads. The effort is part of the “This Is My Squad” program funded by the Army Resilience Directorate (ARD). The goal of SLDC is to empower small teams by developing ethical leadership skills among junior NCOs to effectively lead at the squad level. Skill development includes commitment, culture of trust, and developing others. This is accomplished by combining doctrine from ADP 6-22 and research from the field of human performance, organizational psychology, and positive psychology. The relevance of this work is to create empowered squads that can accomplish a mission in future battlespaces requiring greater autonomy (such as MDO). This program was fielded with the 1st ID in 2021, and participating squad leaders were positive about the training, reported better knowledge scores of leadership principles in the ADP 6-22, and developed their own training philosophy after the course. The ARD is determining future application of the training.

Poor unit culture and climate negatively impacts readiness. The Report of the Fort Hood Independent Review Committee summarizes the problematic climate and culture issues at Ft. Hood (e.g., extremism, racism, sexual assault and suicidality); and, these may persist across other Army locales as well. The People First Task Force Cohesion Assessment Team sought out support for research organizations to measure and implement strategies to improve unit climate and culture in Army units. The goal of the People First Task Force (PFTF) Cohesion Assessment Teams is to foster optimal readiness through healthy unit culture by improving culture and reducing negative behaviors. This is done by rapidly conducting quantitative and qualitative assessments with soldiers and leaders at select units, which identifies any pending issues within the unit and provides recommendations to the leadership with actionable, yet not attributional, recommendations for improving

unit culture and cohesion. The relevance of this work is that strong unit culture built on trust is critical for defeating adversaries, particularly near-peer threats in the future battlespace.

Instilling psychological and mental skills among our Soldiers in an effective manner is paramount for maximizing human performance. Performance experts (with advanced degrees in sports psychology, kinesiology and other related disciplines) are currently embedded at ~32 Army sites within Ready and Resilient Performance Centers across the Army; however, they are underutilized in some cases. The ARD started a pilot program to embed performance experts at the battalion and brigade level, and integrating them into daily activities, to develop resilient Soldiers through coaching methods, as opposed to didactic training. This work is relevant since professional performance coaches build rapport with units and adapt training needs to the unit's challenges; and, the evaluation methods have indicated that the program is a resounding success. Discussions to scale up this training and integrate with the Army's Health and Holistic Fitness Program are ongoing.

Follow-on questions from workshop attendees centered on barriers for implementation of the interventions that have been mentioned herein. Not surprisingly, cost is a barrier, e.g., the units want to scale up PFTF Cohesion Assessment Teams and embedded performance experts. With regard to Squad Leader Development Course, transitioning buy-in from participating units into integrating the training into Army regulations for use is a barrier. Further, in some respects, leader support is tremendous, as is support from the Soldiers undergoing the training; however, in the case of the mindfulness and yoga evaluation in BCT, mid-level leadership buy-in is challenging given the heavy burden that these leaders generally endure. Additionally, integrating reminders to incorporate training actions into daily lives, is a challenge. Lastly, for all training programs, quality control of the original product (i.e., maintaining quality over long periods of time) is challenging.

Far Forward Psychological Assessment and Intervention: Readiness for MDO and Beyond (Dr. Phil Quartana, WRAIR)

Prior work from WRAIR (reference prior section on iCover) has shown that approximately 50% of Soldiers reported seeing impairment related to a combat-related acute stress event. The percentage of individuals that self-reported impaired functioning associated with combat-related acute stress reaction ranges from 5.4% (less than 12 hours) to 12.1% (3 days or more). This emphasis of this work is to preserve emotional, cognitive and physical function for what is now the "Golden Day(s)", given that medical evacuation will take longer in MDO and beyond, compared to the previous "golden hour".

Far forward behavioral health efforts are based on the notion that we will have smaller, more independent, disaggregated teams in the FOE, with limited access to specialty-trained behavioral health care providers and limited availability for timely medical evacuations. This increases the reliance on medics, and potentially squad leaders when medics aren't available, and will require Soldiers to have the capability and opportunity to recognize and self-manage their symptoms. This will rely on an integrated assessment and mitigation of treatment platform, falling into three areas: far forward behavioral delivery systems; cognitive assessment and interventions; and, vocal and other field biomarkers. Currently, with regard to far forward behavioral delivery systems, medics receive behavioral health training for 3 days over 6 weeks focusing on predominantly on self-harm, other harm and psychosis. While important, the breadth of this training is too narrow to be suited for what will be required to maintain behavioral health in FOEs. WRAIR is working with J-9 DHA to develop far forward medic clinical practice guidelines, as well as refinements to initial and refresher medic training

programs for behavioral health assessment and management for use in FOE. BHPulse is an existing behavioral health assessment platform that can provide a snapshot of unit health to target issues for intervention and is now available electronically. However, BH Pulse is currently depending on internet connectivity and is therefore not likely suitable in FOE. Interim work in this area is enhancing medic training and field support and converting elements of BHPulse to a novel assessment and mitigation tool that can function in a closed-circuit non-network manner in FOR (Adapt and Improve in Remote Environment [AIRE] application). This application is in early stage testing and development.

With regard to cognitive assessments and interventions, much of the work is currently focused on the interface between cognition and emotion (e.g., how we attend to threat-related stimuli in our environment). Current efforts with U.S. Soldiers and civilians have been laboratory-based, randomized controlled trials focusing on threat-related bias. We have shown some early promising findings that alterations in threat-related bias prior to deployment can mitigate post-deployment PTSD symptoms (this work was in collaboration with Tel Aviv University and the Israeli Defense Forces; PMID: 27377418). Moreover, we have identified threat-related bias as a moderator of the link between combat exposures and depression and anxiety symptoms in U.S. Soldiers (PMID: 26206076; PMID: 23959788). Interim efforts are focusing on tablet and smart-phone applications for cognitive bias optimization and focus on threat bias, hostility mitigation and friend-foe discrimination. There is also ongoing work with regard to biomarkers. While acute stress biomarkers are well known,

Integrated assessment, mitigation and treatment tools can be used during various scenarios: garrison (e.g., medic training and clinical practice guidelines or CPGs), deployment (e.g., cognitive bias assessment, optimization and modification), Exposure (e.g., passive sensing) and post-deployment (e.g., adapt and improve in remote environments or AIRE) (Figure 18).



Figure 18. Integrated assessment, mitigation and treatment tools during Garrison, Deployment, Exposure and Post-Deployment

Current medic training and clinical practice guidelines (CPGs) for behavioral health are not far forward nor are they focused on MDO and beyond. Efforts are targeting these deficiencies, considering the challenge of integrating new CPGs into training by maximizing training efficiency (e.g., since additional training time is not available). The end state of these efforts is to enhance the breadth and depth of in-garrison training; expand the content and training integration with Deployed Medicine; and, develop medic decision-making assistive technologies (e.g., based on passive sensing indicators and application-based AIRE integrated assessments that can be integrated into a medic dashboard).

Other efforts are focusing on cognitive bias assessment, optimization and modification. Currently most work is lab-based, with some ambulatory or field studies looking at assessing or modifying cognitive bias; however, the latter haven't been particularly successful compared to controlled settings. This work targets three areas: threat bias, inhibitory control and hostility. For training targeting threat bias, the outcome is traumatic stress symptoms. For example, PTSD or anxiety have a differential tendency to attend to threat stimuli and threat-related attention bias is apparent, wherein there are more stress-related symptoms if you are hyper vigilant to threat-related stimuli. Solutions to assess, optimize and modify this bias uses eye tracking, for example, via a mobile phone and/or integrated with IVAS. For training targeting inhibitory control, the outcome is lethality, e.g., training people to avoid shooting things that they shouldn't be shooting at and vice versus. For training targeting hostility, the targeted outcome is aggression. For example, hostility, anger, depression, etc...are common following deployment and are a risk factors for PTSD, thus training Soldiers to be less reactive to stimuli in order to lessen anger and aggression is a mitigation strategy. This work has demonstrated that a 30-min training session has a positive impact on hostility, with benefits extending 96-h post-training, thus providing a simple solution for an effective end result.

Other efforts are capitalizing on passive sensing, with the goal of providing small foot-print solutions down-range. While passive sensing in a closed-loop system is successfully used to identify and mitigate health risks related to physiological stressors (e.g., heat stress), passive sensing to identify and predict acute stress is limited. For example, current efforts are using vocal biomarkers in case-control studies to identify someone with depression and other disorders using vocal biomarkers. This proof of concept work in the lab and field may lead to further application if baseline speech characteristics or stress-related changes co-vary with cognitive and emotional changes.

As mentioned herein, another effort is a post-deployment, application-based assessment program (AIRE) that seeks to assess and provide interventions to mitigate stress. AIRE has four components: check-ins (i.e., daily assessments to identify domains of focus); overcoming stress (i.e., strategies to prepare for, adapt to, and recover from stress); sleep optimization (i.e., strategies to mitigate fatigue and optimize sleep opportunities); and, team communication (i.e., skills to enhance tactical communication and resolve conflict). This application has different dashboards for medics and end-users, allowing for multiple functions and uses.

Panel discussion

As with prior LOE1-focused workshops, attendees continued to indicate that it was helpful to consider their research efforts in the context of the realistic situation presented in the vignette. Observations from the panel discussion regarding the vignette itself, and integration of the vignette into capability development, follow.

In addition to previous observations (Appendix C), additional examples of interpersonal conflict were discussed. There seemed to be a general lack of trust and cohesion among the team members as they're

attempting to set-up the TOC. Additionally, the LT failed to convey the leader's intent to the subordinate. No additional considerations to make the vignette more realistic were discussed during this session.

The panel discussion identified how the capabilities discussed today apply to the vignette, solving problems presented in the vignette and delivering solutions to the protagonist. Themes from today centered on resilience building at the individual, team, and leader level; assessment; and, field-based interventions.

The Sleep Leadership training discussed during the session is a simply intervention that may have far-reaching, positive effects on the obvious sleep-related issues apparent in the vignette. With regard to the general lack of trust and cohesion, leadership training (e.g., SLDC), would strengthen the NCO's (and even the LT's) understanding of leadership principles to create an environment of trust, empowered subordinates, and a shared understanding of the mission objectives. For example, one module in SLDC talks extensively about commitment versus compliance; the interaction between the LT and the first sergeant highlights the lack of commitment in the unit. Related to the work presented in the current session, there are examples of how embedded performance experts communicate with soldiers and leaders at the Battalion level, showcasing their coaching skills and techniques (e.g., deliberate communication) to provide open and clear feedback to unit members. The vignette highlights obvious examples where this type of communication is lacking, and the aforementioned skill development may facilitate communication across echelons.

The vignette also alludes to leadership opportunities where leaders may influence subordinates and it's important to consider what role the leader plays in this scenario. In addition to those mentioned in the vignette, there are other scenarios where Soldiers, leaders and senior leaders encounter a high frequency of acute stress. These experiences provide opportunities to integrate mental skills. For example, Dr. Adler indicated that her group created user-friendly videos to highlight mental skills (e.g., self-talk, deliberate breathing, and grounding to manage anxiety) to ready Soldiers for deployment, specifically addressing acute stress situations where Soldiers can integrate these skills. This type of training may be implemented in various vignette scenarios applicable to Soldiers, leaders and senior leaders, given that Soldiers may not be adequately prepared with the correct skills to cope with acute stress.

Another point of discussion addressed the link between socio-emotional health and physiological health. For example, considering the influence of socio-emotional health on musculoskeletal health and immune function. It is well know that socio emotional health is correlated with immune function, wherein poor socio-emotional health is a risk factor for immune decrements and subsequent respiratory tract infections. Thus, it would be interesting to see how some of the interventions presented herein impact immune health and subsequent risk of illness. Likewise, the influence of socio emotional health on musculoskeletal health and musculoskeletal injury risk deserves further attention. Altogether, this highlights the interdisciplinary nature of the work.

Training approaches to optimize or enhance cognitive capabilities (i.e., science of learning)

February 9, 2022 (MHP LOE cross-over event)

This session was moderated by Dr. Gerald (Jay) Goodwin with assistance from Dr. Gregory Lieberman (Lead, LOE2) and Dr. Tracey Smith (Lead, LOE1).

Introduction (Dr. Jay Goodwin, Army Research Institute)

The Army Modernization Strategy (2019) presents the foundation of modernizing the Army, in the context of “how we fight, what we fight with, and who we are” (Figure 19). When determining how we fight, it is critical to consider concepts, doctrine, organizations, training, and the rapidly advancing nature of battlefield technologies. Modern materiel modernization priorities are the cornerstone of what we fight with, e.g., air missile defense, future vertical lift, Soldier lethality, etc...Lastly, we define who we are by 21st century Talent Management and leader development and education. The red area in Figure 19 highlights today’s topic areas, considering the intersection of the inherently human aspects of readiness (i.e., training, organizations, talent management and leader development) along with hallmarks of training, learning and development (i.e., training, Talent Management and Leader Development and education). Ultimately, modernizing across each effort in a synchronized way will ensure the Army has well-trained Soldiers, organized into effective warfighting formations with modern weapon systems, intelligent technologies, and sufficient capacity to deter or dominate any conflict, on any battlefield, anywhere in the world.

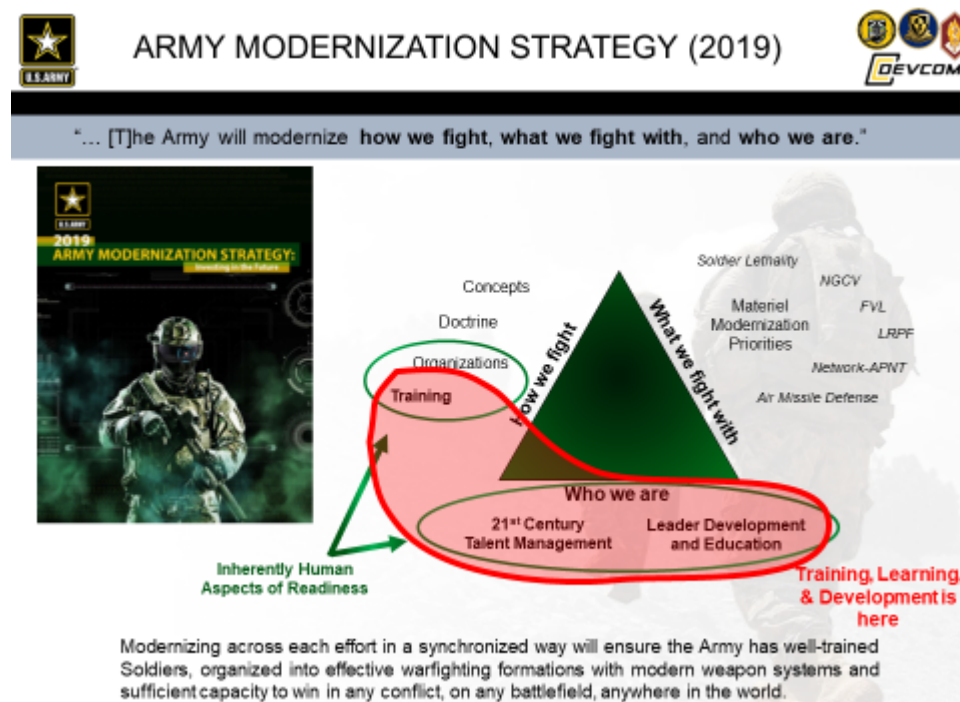


Figure 19. Army Modernization Strategy (2019) and the Science of Learning

There are a number of topics/directions within the context of the “science of learning” that are mentioned within the Army People Strategy, Army Learning Concept, and Army Training Concept. Topics and directions that overlap with the Army People Strategy (2019) include: develop new tools, methods & processes to enhance individual talents; systems to maximize an individual’s talents, but also strengthen weaknesses; continuous development of Soldiers (& Civilians); training and development opportunities to extend Soldier talents; and incorporate a culture of talent assessments into education and development. With regard to the Army Learning Concept (Draft), the following topics/directions emerge: sustain intellectual overmatch; empower learners; learner centric; integrating learning science and enabling technologies; right training and development at the right time and at the right location; learning organization; tailored individual and unit learning; and, data-informed learning infrastructure integrated within Talent Management Enterprise. Lastly, learning science must consider realistic, live, synthetic and complex operational environment which ties to the Army Training Concept (Draft).

The goal for this workshop is to discuss cross-disciplinary topics related to the science of learning. Ultimately, it may be worthwhile to develop a Science of Learning S&T strategy aligned with and supporting the Army People Strategy, Army Training Concept and Army Learning Concept. This will be accomplished by leveraging LOE member organization expertise in cognitive and neurobehavioral aspects of learning (LOE1), learning to effectively team with and adapt to rapid changes in systems and intelligent technology (LOE2). and competency-based on-demand learning (LOE3).

Science of Learning (Dr. Ray Perez, Office of Naval Research)

This workshop focused on three thrusts from the Office of Naval Research program in cognitive science of learning. Thrust 1 focuses on training technologies and exploration of emerging pedagogical strategies for training. Thrust 2 focuses on individual differences, adaptive training systems that take into account individual attributes and abilities (e.g., spatial skills) of trainee to optimize the effects of learning. And, Thrust 3 focuses on neuro-psychometrics and the development of behavioral and neuro-imaging methods to accurately measure the underlying neural mechanisms of learning (e.g., skill acquisition, Posner, 2019; Fitts & Posner, 1968).

Science of Learning Efforts by Small Business in Research (SBIR) Performers

There are multiple SBIR performers for this work. The Model-based Adaptive and Intelligent Naval Training for Operational Readiness (MAINTOR) effort is developing a functional failure-effect causal model as the digital-twin of the Plasma Arc Waste Destruction System (PAWDS) for maintenance training (POC: Sudipto Ghoshal, QSI). This effort will enhance machine reasoning capability of MAINTOR for supporting scaffolding training approaches and human-factors focused software user experience including an intelligent-why capability that facilitates troubleshooting logic comprehension and knowledge retention. MAINTOR will undergo integration with Learning Management Systems such as Moodle and capture trainee performance data and create metrics to evaluate and improve trainee performance. The initial version of the digital twin for maintenance training of the entire PAWDS has been completed, which generates an adaptive troubleshooting strategy with rich media for all alarms/error codes suitable for maintenance training; and, a first draft of the CONOPS has been developed, characterized by learning-science enabled training for PAWDS troubleshooting training and integration with Moodle LMS for auto-populating course content.

Another SBIR effort focuses on an augmented job performance aid, specifically developing and evaluating a scientifically-grounded pedagogy (MASTER) and Scaffolding of Stressors, Complexity, Assistance, and Fidelity

(SCAF-folding) strategies for the use of XR in transferring domain knowledge and supporting skill acquisition across the proficiency continuum (POC: Kay Stanney, Design Interactive). The development and evaluation of an XR-based tool (EXTRACT) is in underway for extraction and preservation of expert domain knowledge. This work will apply the pedagogy to design and develop appropriate training scenarios based on the MASTER pedagogy, SCAF-folding guidelines, and knowledge elicited via EXTRACT (Claypoole et al, 2020; Claypoole et al, 2021).

A third SBIR effort focuses on simulating training results to understand differing effects of fidelity on learning (STRUDEL) (POCs: Peter Weyhrauch, Charles River Analytics; and, Frank Ritter, Penn State University). This project develops Methodology for Annotating Skill Trees (MAST) to explicitly model fidelity, tasks, and skills. Behavior-based AI will implement troubleshooting models (focused on Naval troubleshooting) (Ritter & McDermott, 2020). Additional highlights of this effort include: ACT-R and its learning equations were applied to Hap AI system to simulate effects of fidelity on learning; hardware task with variable-fidelity game-based training simulations to test learning in multiple fidelities; editor and visualizer for capturing and sharing research results on fidelity (recommendation engine); developed troubleshooting tutors for each level of fidelity. Started running study with lower, medium, and high fidelity troubleshooting simulations; and, converted analysis completed for ICCM 2020 from Excel into R for further detailed analysis.

Training Return-on-Investment Analysis, Investigation, and Evaluation Reasoning (TRAINER) Toolbox is another SBIR effort (POC: Peter Weyhrauch, Charles River Analytics). The TRAINER Toolbox ingests and analyzes curriculum information and training data to provide evidence-based guidelines about the appropriate fidelity and sequence of training. More specifically, thus far, this effort developed underlying ontology and analytical model; developed model specification language and ingestion algorithm; implemented net API and command line application; modeled T-44, T-6 syllabus (event, maneuver, and skill level); modeled pilot performance data T-44, T-6; analyzed alternatives applying AR to checklist training T-44; imported historical Navy pilot performance data; and, developed Prof. Adv. Tool (PAT) for CNATRA (initial version).

Another effort is accelerating acquisition of tactical expertise in ill-structured combat settings (POC: Lia DiBello, FutureView™ @ ACSILabs). This effort is designing an immersive multiplayer game in which players have to accomplish a high stakes mission under highly uncertain conditions. Accelerated learning principles are derived from Cognitive Flexibility Theory and Cognitive Transformation Theory. This effort will train USMC senior enlisted leaders in tactical principles for urban combat settings with high uncertainty; measure a treatment and control group in a realistic combat simulation; and, conduct a formative evaluation design that will test the effectiveness of the accelerated learning strategy and the combat training game.

The Doc-In-A-Box effort seeks to develop a state of the art Information Retrieval (IR) and Question Answering (QA) System on top of a dozen digitized medical books (POC: Chitta Baral, Arizona State University). This would allow a Navy medic access to the system anywhere (even in a place lacking in Internet connectivity) to deal with medical issues and emergencies and make appropriate diagnosis. The longer term goal is to develop a natural language dialogue system that the medic can interact with under the above circumstances. This effort is addressing several contemporary technical challenges that include neural network based Information Retrieval (IR), Question Answering(QA), and differential diagnosis. The goal is not just to build such a system, but to do better than what is currently available, and address various associated challenges. For example, a Navy medic has limited time, therefore it's a challenge to improve on existing IR and QA techniques so that the system can give high rank to the right document, the right text in the document, and the right answers (i.e., these cannot be buried deep among the results as the medic may not have much time to go down the list and

eliminating the irrelevant top ranked results). As such, the focus is on new semantic search techniques. Scientists are proposing a new notion of “Semantic (missing) information Availability”. Further, searching with medical text is an added challenge, in that medical ontology is chaotic, with a wide variety of synonyms, entity recognition in text (e.g., gene names), and clinical jargon.

Training Technologies

In addition to the SBIR work, ONR core performers are studying training technologies to facilitate learning. For example, one effort focuses on unifying principles and metrics for safe and assistive artificial intelligence (AI) (POC: Siddharth Srivastava). This work is motivated by the fact that the value of shipboard AI is undermined by the need for extensive training to ensure safe operation. This project is developing principles and algorithms of Troubleshooter AI (TAI) systems that autonomously improve users’ ability to understand limits and capabilities of black-box AI systems; understand AI behavior; and, predict outcomes of new instructions and re-tasking (Srivastava et al, 2021; Verma and Srivastava, 2021).

Another effort related to training technologies is focusing on tight-loose (TL) ambidexterity, specifically exploring how leaders can effectively balance freedom and constraint (POC: Michele Gelfand). This work is using interviews, surveys, experiments, and computational linguistic techniques. Interviews with the Navy have helped to identify challenges that units have in achieving TL ambidexterity and the team is working with N17 to deploy a survey across the Navy. Scientists have developed new experimental paradigms to study how teams can achieve a balance of order and openness. Other research has focused on societal and organizational resilience during COVID-19--in particular the cultural norms that help limit cases and deaths as well as which help organizations maintain productivity. Accomplishments include the design of a new threat dictionary to track the cultural, political, and economic shifts that occur in response to threats in the U.S. across the last 100 years.

The training technologies focus area is also studying strategy development and adaptation in problem solving (POC: Jarrod Moss). The overall goal of this work is to develop a theory of strategy development and selection in problem solving that accounts for individual differences and has strong connections to theories of training and transfer. Scientists are examining the impact of individual differences on representation and strategies used on a problem; the individual differences in how a problem attempt guides strategy selection on next attempt; and, modeling the interaction of component cognitive systems in accounting for these strategy differences to identify points of maximum impact for training (Wong & Moss, 2021; Jones & Moss, 2019).

Action video games are another focus area with regard to training technologies, e.g., key components of video games and their neural underpinnings (POC: C. Shawn Green). Research has shown that action video game experience produces enhancements in a broad range of cognitive functions, including many cognitive functions that are essential in Naval personnel (e.g., attention, multi-tasking, spatial skills). Because action games are highly complex, it is unclear what particular game characteristics are critical in driving these improvements. This is problematic due to difficulty in building training platforms specifically for impact. Scientists used a multi-pronged approach to examine the possible critical game characteristics: examining the impact of games that partially overlap in terms of their gameplay characteristics with action games (i.e., action-RPGs, action-RTSs, MOBAs, etc.); using a custom-built research action video game that allows specific game play characteristics to be titrated; and, using an advanced machine learning approach to map the 2D space of commercial video games.

Findings from fMRI and ERP studies targeting training technologies for future learning (POC: Daphne Bavelier) have demonstrated that the performance superiority of video game players (VGPs) is based at least in part on a more efficient attentional control network, which modulates feed-forward signals at early stages of visual processing. This modulation includes both amplification of attended inputs and suppression of irrelevant, distractor inputs. These findings mesh well with a neural model proposed by Pouget and Bavelier, which postulates enhanced feed-forward visual signals as a basis for improved perceptual discrimination in VGPs. By revealing the underlying neural mechanisms, electrophysiological and neuroimaging data can help to develop and validate both neural and cognitive models of VGP performance superiority.

Lastly, in the area of training technologies, ONR is studying how to improve adults' source-based writing using adaptive reading and writing instruction (POC: Danielle McNamara). This work is developing an automated, adaptive intervention to improve adults' source-based writing. An intelligent tutoring system will use a hybrid game-based design allowing users to choose multiple types of game-based and non-game practice methods adaptive to individuals' needs and characteristics. Scientists have created new summarization and question asking strategy practice modules; designed and initial development of source-based writing practice module; and, conducted an individual difference study examining relationships among reading, writing, and source-based writing skills. Currently, scientists are conducting an implementation study examining reading and writing instruction in a military journalism classroom.

Individual Differences

ONR core research is also studying individual differences with regard to learning. The first effort focuses on assessing and improving military personnel's metacognitive ability (POC: Dobromir Rahnev). This work is creating and maintaining the Confidence Database, the largest database of confidence studies, which will be used to test a new measure of metacognition. A recent model was developed with a new measure of metacognition, which specifies the nature of metacognitive inefficiency and model testing is underway. Using the improved measure of metacognition, scientists are testing several training paradigms for improving metacognitive ability (Rahnev, 2021).

Another effort is studying the effects of sleep deprivation and individual differences on procedural place-keeping (POC: Erik Altmann). The overall goal is to investigate place keeping, a cognitive ability required for accurate performance of procedural tasks. One track of the project measures impairments in place keeping caused by sleep deprivation and test interventions to mitigate them; and, the other track of the project, aims to predict individual differences in place keeping and in susceptibility to impairments caused by sleep deprivation, for use in personnel selection and classification (i.e., selecting good place keepers) (Burgoyne et al, 2021; Stepan et al, 2020).

Lastly, efforts are underway to examine comprehensive spatial testing for selection and training (POC: Mary Hegarty) (Hegarty & Waller, 2005; Wolbers & Hegarty, 2010; Friedman et al, 2019). This work is developing online versions of comprehensive spatial testing tasks and administration of these tasks to large samples representative of navy recruits. Further, scientists are examining psychometric properties of online measures of each ability, and correlations between these measures, to identify the best combination of tests and test items for efficient and reliable measurement. Additional efforts are underway to review tests of cross sectioning ability; develop and pilot online measures of this ability; review measures of navigation ability; and, adaptation of measures of navigation ability.

Neuro-psychometrics

Office of Naval Research also has efforts focused on the neuro-psychometrics associated with the science of learning. The first effort is working toward a neural model of human skill learning (POC: Michael Posner). In human studies, MRI was used to assay white matter (DTI) and grey matter (BOLD) changes following two weeks of working memory or meditation (IBMT) training. Used reaction time tests to explore if changes in white or grey matter are correlated with behavioral change. Constructed learning curves showing accuracy in the skill improved as a power function of days of practice. Suppressed mouse learning by laser stimulation of anterior cingulate (ACC) and hippocampus (HC) demonstration suppression of the ACC reduced performance during all above chance stages of learning; and, suppression of the HC reduced performance in the middle and late stages of learning. Related studies also examined genes from the mouse brain that were down or up-regulated following rhythmic stimulation. Subsequently, this was used to examine the HC, ACC and visual areas of mice who have undergone skill learning; and, comparison of mouse and human blood following learning to see if there are common changes in gene regulation in the two organisms. This work provided new evidence that mice can serve as a model system for human studies; demonstrated parallel activation of attention and memory networks; and, developed a model linking attention to memory networks and detailing their relation to behavioral stages.

The neurocognitive basis of knowledge acquisition (“building better brains”) is another area of focus in ONR’s neuro-psychometrics work (POC: Marcel Just). Objectives of this work are to understand both the cognitive and neural mechanisms through which new concepts are learned; to map out scientific knowledge in experts; and, to map (and re-map) novice brains before and after training. The latter involves determining training regimens that leverage brain science and performance prediction. This work encompasses three projects in which novices are taught functional properties: mechanical systems, physics concepts and natural categories (animals); and, outcome measures include neural (fMRI, HARDI DTI) and behavioral measures. Thus far, this work has determined existence of 4 cortical networks of physics properties entailing processes such as causality and visualization (Figure 20, top); and, found three stages in the acquisition of functional knowledge of mechanical systems (Figure 20, middle). More specifically, learning begins with visual processing of novel systems; inferences about causal functions are then generated; and, final stage: imagining how one interacts with the system. Additionally, scientists have discovered that natural category neural representations are established as relevant features are learned (learn first about habitat of animals and then diet of same animals, or vice versa); and discovered neural representations as they are developed via training (Figure 20, bottom). Additional work in this area is investigating knowledge acquisition (learning) from short expository technical passages in a near real-world task; determining sources of individual differences in learning from text using fMRI; advanced paradigm development to study a complex real-world learning task with functional brain imaging; predicting learning performance based on brain activation characteristics and psychometric measures of cognitive abilities; and, identifying the neural representation of specific knowledge (i.e., specific thoughts) (Mason et al, 2020; Mason et al, 2021; Vargas et al, 2020; Vargas et al, 2021).

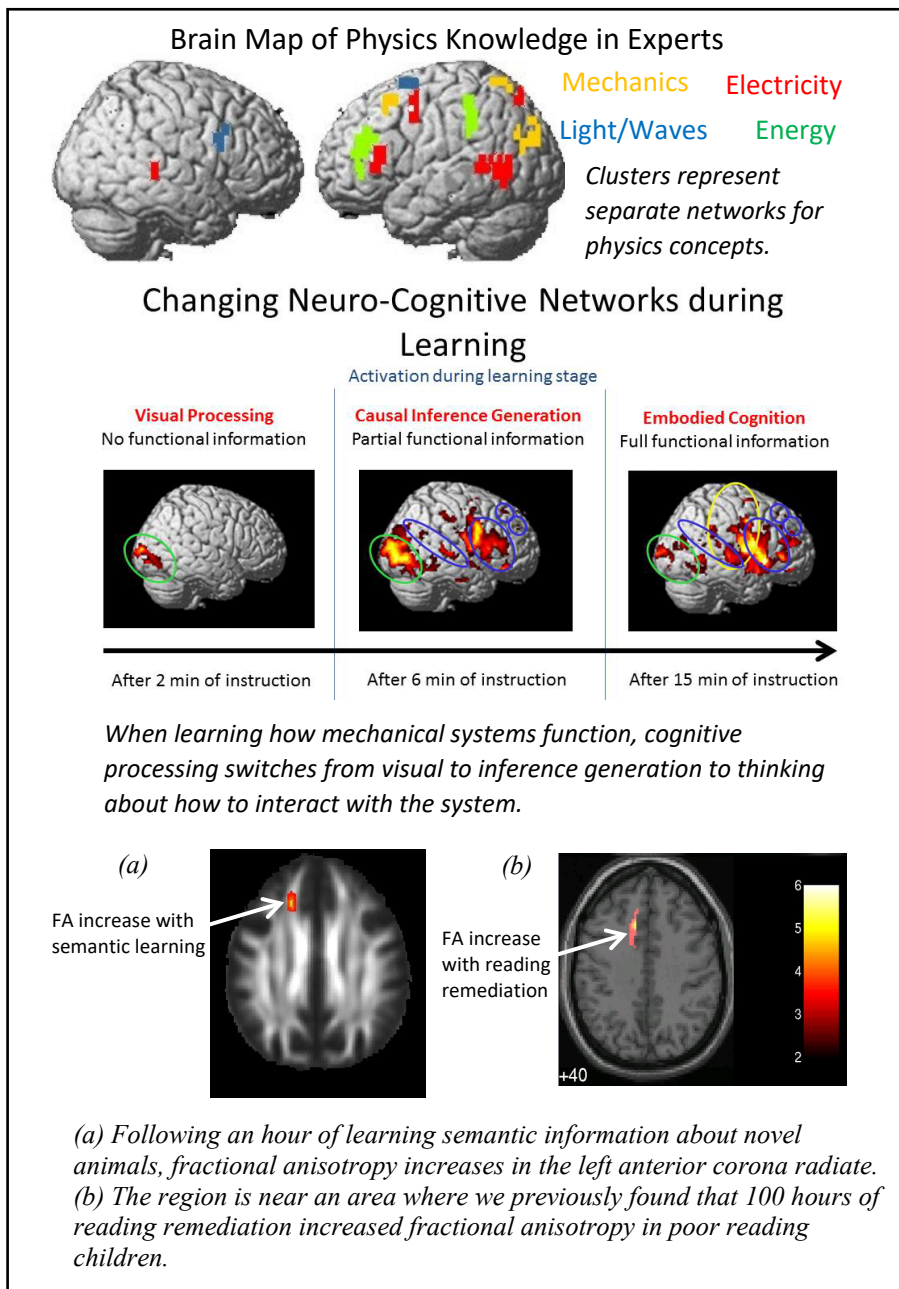


Figure 20. The neurocognitive basis of knowledge acquisition: building better brains

Another area of focus is learning complex cognitive skills, specifically bridging neuroscience and education through individual differences research (POC: Chantel Prat). Efforts are comparing the neurocognitive predictors of learning natural language (2nd language) to those that predict learning programming languages; and, applying experimental research involving complex skill training and computational modeling. Cognitive and neural (fMRI and EEG) batteries are collected prior to 8-10 hour training sessions and used to predict various facets of complex skill learning such as learning to speak in French or learning to Program in Python. Current experiments are relating resting-state fMRI and EEG to differences in declarative and procedural learning; and, using resting-state data to predict Python and French learning.

Dr. Perez concluded by highlighting the cognitive science of learning program accomplishments. The program has demonstrated that action video games can be used as a training regimen for a wide variety of skills, ranging from perceptual skills (how one sees) to attentional skills (selecting a target amongst detractors) and cognitive skills (task-switching, visual memory). They have identified major changes in top-down attentional control fostering wide transfer- brain imaging studies revealed plastic changes in the parietal cortex and frontal projections (fMRI, ERP, modeling of neural network of spiking neurons) recruitment is lowered in expert VGP. The program has gathered evidence demonstrating an increase in learner rates and transfer in VGP's in several domains, including perceptual learning, decision making, and statistical learning. Findings have proven that action video game training leads to unprecedented transfer of learning by facilitating learning-to-learn. The program has also identified an optimal training regimen for a wide range of tasks - vision, attention, cognition and decision making. Lastly, scientists have identified training environments that promote optimal decision making and enhanced learning abilities.

Intelligent tutoring for collective training (Drs. Joan Hall Johnston, Gregory Goodwin and Benjamin Goldberg, DEVCOM, SC)

A MHP cross-LOE initiative for a Learning Science S&T strategy centers on the necessary S&T to investigate educational and training innovations to maximize Warfighter employment of the new capabilities arising from MHP S&T. As indicated herein, LOE1 inputs will include **the cognitive and neurobehavioral aspects of learning**; LOE2 will address **learning to adapt** to rapid changes in systems and technology and LOE3 will address the integration of talent and learning management systems to plan and implement competency-based on-demand learning strategies (i.e., **application of learning**). A cross-LOE Science of Learning S&T strategy will formulate a unified plan that aligns with the Army's Concepts for Operating, Learning, and Training by 2040 and accommodates future cross-LOE initiatives that are likely to arise.

With regard to the Synthetic Training Environment (STE) training management tools and training effectiveness, the goal is to develop automated team assessments, feedback mechanisms, and after action reviews (AAR) for training along with intelligent, adaptive training tools and techniques for teams. The impact of this work is reductions to the time & cost needed to deliver collective training in the STE; personalized training based on objective measures of readiness and team characteristics; and a persistent data strategy to manage data across an ecosystem of training and education resources to monitor performance over time and to infer proficiency and readiness. One issue/risk is that obtaining broad access to training and personnel data may limit the ability to develop detailed/validated models. Currently, collective training of Units relies heavily on subjective human assessments; and, permanent records of unit training have limited information related to unit performance and trends in performance. Limitations and gaps of this approach are that performance measures are not tracked over time and do not allow for systematic analysis; and, it cannot support big data and AI research to improve training enterprise (Goldberg et al., 2021). The proposed approach includes automated assessments in virtual, constructive, and live training; leveraging big data tools to quickly assess outcomes, support automated feedback, and enable intelligent tutoring; and, creating individual and team competency frameworks to track unit performance across all learning domains and training modalities.

In terms of automated team assessment, the overarching goal is to create validated prototypes for automating team assessments. This is relevant to STE in that providing objective team performance measures is a cornerstone of team collective training. The Army currently relies heavily on human observers to provide these measures. The rapid creation of automated, objective team assessments will significantly reduce the

cost and labor needed to conduct performance assessments in STE. This project focuses on identifying methods for automating assessments of teams and validating those methods in relevant use cases; and, testing tools and methods for rapidly configuring team assessments based on training objectives and context of interaction. There are multiple near-term deliverables for this work: Data/Metrics for training effectiveness and trainee evaluation prototypes for visualization of Command Post (CP) communications and assessments of forward observer training (FY19); tool for generalizable team performance assessment for platoon and below for defined battle drills and automated assessment algorithms for teams (FY20); performance visualization testbed for BDE and below validated using Combat Training Center—Information System (CTC-IS) performance data (FY21); and, natural language classifiers for small team verbal communications during procedural task execution (FY22).

With regard to automated feedback and after action reports (AAR) for teams, the goal is to create validated prototypes for automating and visualizing team assessments for real-time feedback and AAR workflows. This is relevant to STE, in that units conducting training will not have expertise in data analytics and thus will need methods and tools to easily help them to visualize outcomes of training events in ways that are meaningful, actionable and that ultimately result in more efficient and effective training. This work focuses on prototype tools and methods for providing teams with appropriate feedback and AAR so that team members have a clear understanding of team strengths and weaknesses; and, feedback tools and methods will have to consolidate and contextualize a wide range of biometric, voice, and performance measures linked to training and mission objectives through the utilization of AI and ML technologies. Near-term deliverables include: automated AAR tool for SQD and PLT battle drills (FY21); automated AAR for CO collective training (complex mission) (FY23); and, automated AAR for CP collective Training (FY25).

There are also efforts addressing intelligent, adaptive training for teams. The goal here is to build a robust team adaptive training capability to maximize training outcomes at all points of need. This is relevant to STE given that it is necessary to adapt training events to learners in order to ensure efficient and optimal skill acquisition/growth. Currently this requires highly experienced/trained instructors. By building in artificially intelligent tutoring capabilities, STE will be able to deliver much more efficient and effective training aligned to skill acquisition best practices at a lower cost than is currently possible. This project focuses on developing AI methods grounded in learning science to support self-optimizing systems that produce skill retention and transfer into the operational environment; and, providing authoring tools and workflows for training developers to rapidly configure adaptive training solutions. Near-term deliverables include: exercise control tools and testbed developed and validated at CTCs for BDE combined arms collective training (FY22); intelligent tutor with automated exercise control and AAR for CO collective training (complex mission) (FY23); and, intelligent tutor with automated exercise control and AAR capability for BN command post collective training (FY25).

Figure 21 shows the objectives for the STE Experiential Learning for Readiness (STEEL-R) effort.



STE EXPERIENTIAL LEARNING FOR READINESS STEEL-R OBJECTIVES



Figure 21. STE Experiential Learning for Readiness STEEL-R Objectives

The STE management tool began in FY19 (technology readiness level 4) and will complete in FY23 (TRL6); and, the effort has nine remaining transitions that will have significant impact in this field. **The Generalizable Assessment Tool** reduces the time and effort needed to create team level assessments. It uses a standardized template for team performance assessments with Intelligent Tutoring modeling techniques. At run-time, it will monitor interactions and behaviors to assess performance. **The Performance Visualization Testbed (all echelons)** has a plug and play interface for sharing data across multiple display modes (e.g., Virtual Reality, Augmented Reality, Floor Projection, and Sand Projection). The tool is built on a service-oriented architecture that establishes a standardized interface for any STE component or device, and provides immersive interfacing to support adaptive and intelligent exercise control. **The Auto-AAR (PLT and below)** is an easy-to-use capability that supports the authoring of a library of feedback prompts, supports, questions, and scenario adaptations STE can enact based on the performance assessments being captured in real-time. All strategies can be automatically delivered through TMT, or managed by the OC/T. This tool interfaces with the generalizable assessment tool and automatically creates a 'Scenario Playback' with the task storyline and performance outcomes visualized on a searchable timeline that combines all data feeds with the assessment model to support reflective and objectively informed AARs. **The Experiential Learning Auto-xAPI Generation** is a capability that provides a service extension to the Generalizable Assessment Tool and enables the auto-generation of performance statements in the eXperience API (xAPI) data format, which is a designed specification to enable data interoperability linked to assessments and experience outcomes. This data is used for longitudinal tracking across all xAPI compliant training and education resources and maps those experience data to established competency frameworks designed to track KSAA's (Knowledge, Skills, Abilities, Attitudes) critical to team proficiency and readiness. The tools and data services associated with **Natural Language Classifiers** will apply automated methods to track and assess Soldier and team communications within the context of a scenario and its objectives. Classifiers will be used to monitor the flow of information and sequence of communications to measure multiple team dimensions linked to situational awareness and cohesion. This will support better diagnostic assessments in STE and will be applied within auto-generated AARs. **The Infantry PLT/SQD Competency Model** will transition an operationalized definition of KSAA

structures built in the Competency and Skill System (CaSS), an open source tool used to establish operationalized definitions of competence that will be informed by performance data captured at the training edge. This leverages the FY20 transitioned Generalizable Assessment Tool and xAPI auto-generation service to use evidence captured in training to infer overall individual and team competency ratings across critical task lists. This capability is designed to extend beyond STE, and can support interaction and performance tracking across an ecosystem of resources. Lastly, the **SQD Smart Assessment Engine** will enable automated assessment of Call for Fire TTPs across ATAK and radio-call input modes of interaction. The assessments will also account for team roles and behaviors of a Forward Observer in a collective context. The assessment engine is being integrated in the Generalizable Assessment Tool.

Future research in these areas (FY23-27+) is focusing on competency-based training for MDO. Goals are to create a new common MDO Competency Framework to drive machine-supported training performance data collection, tracking and readiness projections; and, establish data interoperability standards to create a common view of learners and how learners operate and navigate in the cognitive, affective, and psychomotor domains. Project focus areas include: modeling of knowledge, skills, abilities, and attitudes across MDO task structures; developing re-usable measures of performance/effectiveness (MOPs/MOEs) applying synthetic data sources; developing data ontology and algorithms to map measures to competencies; creating dashboards and UIs for competency profile visualization; bridging competency profiles with autonomous forces policies; and, developing AI-driven recommender engines to accelerate readiness. Deliverables include: automated assessments of critical MDO skillsets; visual recommender engine for guiding training emphasis targeted to individual and unit needs; and, accelerated mastery of MDO mission sets through deliberate practice.

Panel discussion

During the panel discussion the following topics were addressed:

With regard to STEEL-R, the panel detailed and discussed the journey between novice to expert. STEEL-R establishes the infrastructure to drive a data strategy with collection of experiential evidence across the learning inject points. With regard to moving from novice to expert, this starts at the institutional level and translates into operational and moves beyond achieving the “standard” from a performance standpoint and being able to build in formalized delivered practice into a long range training calendar that adheres to what is required to achieve an expert performance status across a competency or set of tasks. Ultimately, from a crawl, walk run paradigm, this model is trying to identify evidence profiles within crawl acquisition curve, walk acquisition curve and run acquisition curve. This involves understanding the exact knowledge and skills that are stimulated in the early exposure events (e.g., understanding the spectrum of extended reality and how they support different levels of fidelity) and as learning enhances, fidelity increases. With regard to stimulation, we can target early skill sets and knowledge components to create robust schema within the brain that hopefully transfers to a more complex, dynamic environment, while establishing evidence-centered data repositories used to refine and optimize these skill acquisition curves. All of this ties together with other existing efforts in learning science and cognitive science (e.g., best practices for learning strategies) and STEEL-R focuses on an extensible strategy designed for tracking data across all of those areas to build data driven models.

Further discussion ensued regarding what this learning process would look like if it was only partially contained within STE. For example, with regard to marksmanship, some of the training takes place virtually, while other training takes place in a field training environment (on a static range or live-fire training scenario). Thus, how

do we map that same set of information across those contexts and how do we get to a point where they can actually understand the skill as it is being developed across the range of skills regardless of the context. The current approach is to establish evidence profiles, understanding that certain resources may only provide evidence that someone is showing and understanding the knowledge component but we are lacking the evidence that someone can apply it in a live environment. At the collective level, within STE (synthetic, first person shooter), for example using it to help train and influence engaging targets with M4 competency, there are going to be very specific items of evidence that we want to extract from that simulation that can be used to build assertions. If someone is not shooting accurately in a simulation, and we're getting that metric that they have no ability to execute, the data will be discarded because it doesn't provide an assertion that the person will hit a target in the real world. However, we can look at other metrics, e.g., how well they are monitoring a sector of fire, how well they are identifying targets and determining if a target is a threat, how well they are communicating across the structure. This incorporates cognitive elements that can be used to build evidence showing that if we put them into a live situation, they will at least have these formal skills in place. i.e., it considers evidence points of competency that needs to be confirmed in a more dynamic environment. Building these layers of evidence over time, and based on the learning experience, will dictate the type of meaningful assertions that we can make from that data. It will also help identify best practices for the application of simulation STE to drive overarching competency development within a crawl, walk, run paradigm. We expect some kind of progression through computer based, mixed reality, controlled training experience and pushing them into live fire experiences which are resource intensive, expensive and time consuming and limited exposure, incorporating the skills so we're getting the most out of that interaction. Altogether, it's important to create this index that links an experience or type of metric that one can consume and how that actually can assert confidence.

This issue is a big challenge and has been for a number of years. That is, we've introduced simulation into training paradigm, but we don't have a ready way to move across different types of training environments in a meaningful way. The panel speculated as to how we can solve this problem. The way we traditionally have framed the problem is to understand that when you're doing a front end analyses of any training system, you're focusing on what the system can train and what can't it train. The idea would be to think of the major domains of learning (e.g., cognitive, psychomotor, affective). For example, in a desktop or laptop virtual simulation, we're not training psychomotor skills (e.g., clear a malfunction from your weapon), because the system doesn't afford the training of those types of things. However, we can train decision-making, situational awareness, and communication skills fairly well using this type of training. As a starting point, we begin to map all of those training systems and define the competency in a more complex way (i.e., what are the aspects of that competency across the domains) and which training events address those various elements of that competency and which kinds of training provide that exposure for skill development. Over time, the Army has the potential to generate a large amount of training data, but better use of that training data (following an individual across training events) and e.g., analyzing and validating that data, can lead to application and enhanced learning. Over time, that data can drive the models, and be used to validate the training/learning models.

An important focus area for 2040+ is tactical operations skills and the ability to visualize what's coming at you, for example. In terms of the POM23 program, presented by STTC, one of the areas is looking at the competencies that are in play at the tactical, operational levels and then using technology to stimulate those competencies. For example, how does one maintain situational awareness with information overload; how does one decipher information from actionable intelligence; how does one interface with robotic teams

(internet of things). That is a future area of focus, and the investigative team looks forward to feedback from the collective SMEs in this area with regard to the elements of performance.

In relation to future research areas presented by STTC, the importance of gathering SMEs to synchronize with regard to the characterization of knowledge, skills, abilities, behaviors, competency and performance was emphasized. This future discussion will also consider existing, related efforts that are underway, e.g., to define competency structure that can be machine readable and predictive validity of competencies. The end point of this focused effort is a more integrated perspective on training and personnel management all falling within the umbrella of talent management, to include what our personnel can do and the related skills.

Monitor, assess, and predict health outcomes

February 14, 2022

This session was moderated by Dr. Tracey Smith (Lead, LOE1).

Musculoskeletal Health and Performance in 2035 and beyond (Dr. Julie Hughes & Dr. Stephen Foulis, USARIEM)

Musculoskeletal injuries in Warfighters have been recognized for over a millennial. Repetitive loading injuries in bones, called stress fractures, were first recognized in Prussian Soldiers in the mid-1800s, and are unfortunately still a problem for modern militaries. For example, according to Army Public Health Center, injuries are the leading contributor to medical profiles and non-deployable status in U.S. Army Soldiers, affecting 154,000 Soldiers annually, accounting for 10 million limited duty days. Of these injuries, musculoskeletal injuries or those affecting muscle, bone, tendon, and ligaments, are the most predominant. Musculoskeletal injuries are most common during initial military training when trainees undergo substantial physical exercise. Trainees who sustain an injury during initial military training are more likely to get medically discharged.

A Soldier's musculoskeletal system is key to human performance, and is even an important determinant of overall health, with recent research identifying that musculoskeletal tissues act as endocrine organs capable of influencing human physiology. The musculoskeletal system is sensitive to the prevailing mechanical and hormonal environments, and ensuring the health and strength of the musculoskeletal system requires knowledge of how the multiple stressors experienced by Warfighters influences it.

There are two primary end state goals of Military Operational Medicine Research Program's (MRDC) injury prevention and reduction strategic plan. The first is to minimize the threat of musculoskeletal injuries. While it is unrealistic to expect that musculoskeletal injuries will ever be completely abolished, given the physical nature of Warfighting, minimizing the threat to reduce prevalence is key to optimizing and enhancing Warfighter health and performance (i.e., the second end state goal). The latter of which will contribute to strategic advantages in the future operational environment. Research related to this strategic plan is leveraging extensive intramural (Army) and extramural collaborations (e.g., DoD and academia) in various disciplines to tackle this multi-factorial problem.

One of the reasons musculoskeletal injuries are still so prevalent in the U.S. military is that the causes are multifactorial, and their pathophysiologies are still being characterized. It is important to first understand what risk factors are most important, in order to identify solutions to reduce injury risk. USARIEM is in the final year of data collection for a large field study (ARIEM Reduction in Musculoskeletal Injury Study, or ARMI) in which

investigators are investigating a comprehensive list of traditional and novel risk factors for musculoskeletal injuries (Figure 22). By answering key questions (Figure 22), investigators will provide evidence-based, actionable recommendations to Army leadership for strategies to reduce musculoskeletal injuries in Army recruits.

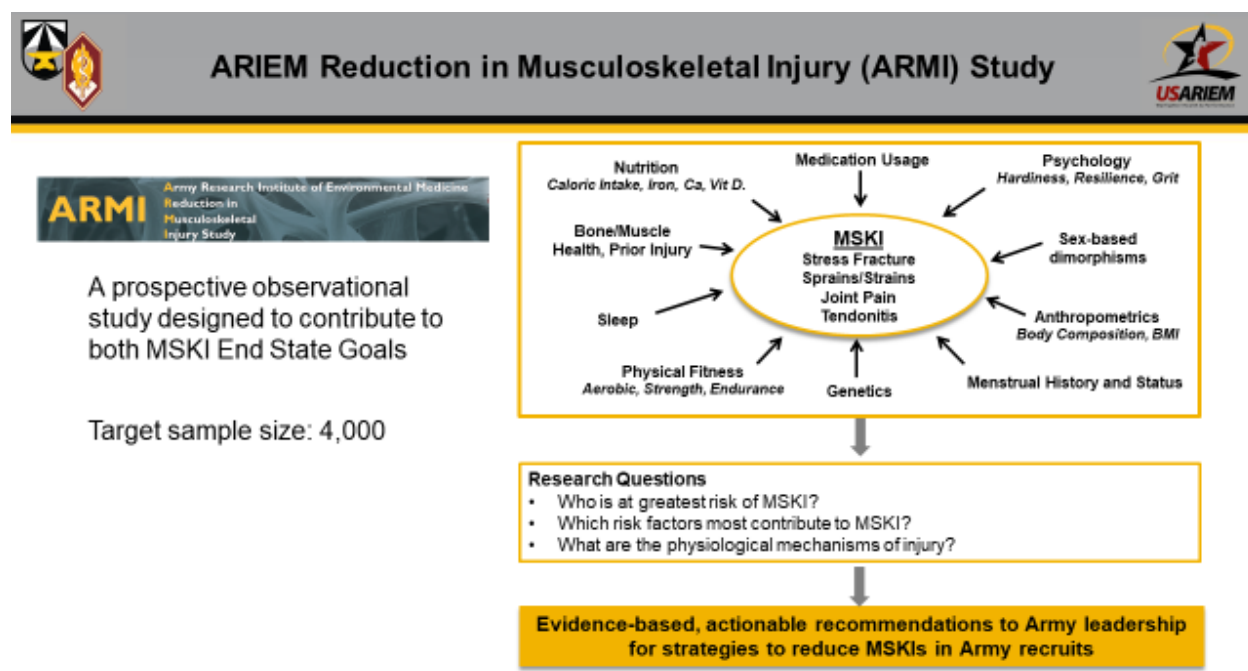


Figure 22. ARIEM Reduction in Musculoskeletal Injury (ARMI) Study

This study involves fasted blood draws, gold-standard measurement of body composition, high-resolution bone scans, and surveys of medical and lifestyle history at the beginning and end of the 10 weeks of BCT, as well as weekly injury surveys, and injury data for two years after data collection. To date, data has been collected on 3,620 volunteers, with most coming from the 3-39 Infantry Battalion (Ft. Jackson). Data collection is scheduled for completion Summer 2022.

Preliminary results have emerged from this data, particularly from medical records on the first 2800 participants. Data indicates that 68% of women had a musculoskeletal injury that was severe enough to seek medical care and receive a diagnosis from a medical provider. Injuries were also common in men, with 40% of men receiving a medical diagnosis for a musculoskeletal injury. Most of these injuries were in the lower limbs. Investigators will link this injury data to other outcomes to determine who gets injured, why they get injured, and how can we prevent injury.

Women's health issues, and associations with musculoskeletal health and injury risk, is another prominent area of research. An ongoing investigation of women's reproductive health is studying how menses change during basic training, and associations with injury risk. Findings indicate that nearly 40% of women who arrived at training with regular menses, missed at least one period during BCT with 86% of women reported some disturbance in menstrual health during BCT. These data provide some evidence of how widespread the problem is and may offer up new risk factors and opportunities for injury prevention in female Warfighters.

In another partner study (PI: Dr. Kristin Heaton, USARIEM), investigators are studying the mind-body connection in musculoskeletal injury. Results indicate that ~70% of trainees self-reported having an injury during BCT; and, trainees with high scores on grit and positive hardiness subscales at the start of BCT had 20-30% lower odds of self-reported injury during training than those with low scores at the start of BCT. Further, trainees with high scores on negative hardiness subscales at the start of BCT had 20-40% greater odds of self-reported injury during training than those with low scores at the start of BCT. Further work is necessary to understand the mechanisms underlying these relationships, but these data provide novel evidence linking psychological characteristics and MSKIs, underscoring the need to include psychological factors, not just physical and demographic factors, when determining MSKI injury risk.

The aforementioned results are examples of how collaborative work and combined subject matter expertise can reveal new, promising risk factors and related solutions to injury. In a collaboration with bone biologists, physiologists, and engineers, USARIEM has led the drive to create a new working model of stress fracture physiology (Figure 23). In summary, the negative feedback loop on the far left depicts the process of detection and repair of bone tissue that can lead to temporary bone porosity and ultimately stress fracture. This has been the focus of stress fracture pathophysiology for decades. A different physiological process involves detection of novel mechanical loading from physical training and subsequent anabolism, which holds great potential in not only preventing stress fractures but also for creating a stronger skeleton that would be capable of withstanding the many stressors seen in the operating environment.

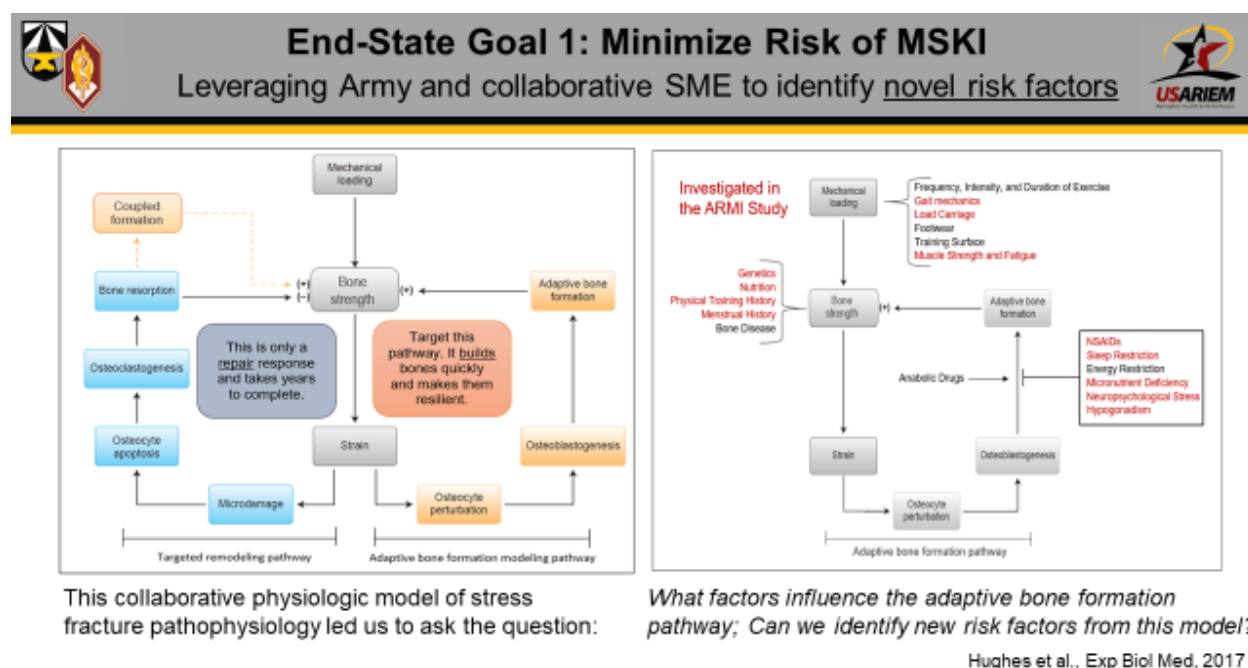


Figure 23. Leveraging Army and Collaborative Subject Matter Experts to Minimize Risk of Musculoskeletal Injuries

This anabolic feedback loop is pictured by itself on the right side of Figure 23, and at USARIEM, investigators are building collaborations to reveal the many potential factors that may influence this adaptive loop. Many of these factors are being studied in the ARMI study but are also leading to more focused investigations as well.

An example of the aforementioned efforts focuses on nonsteroidal anti-inflammatory drugs (NSAIDs). NSAIDs are some of the most commonly used analgesics in the Army with nearly every soldier receiving a prescription or using it over the counter for pain reduction purposes each year. Animal studies indicate that NSAIDs inhibit the production of prostaglandins which are proteins that are needed to induce bone anabolism with exercise. An ongoing population-level analysis using the SPHERE database (a longitudinal database discussed herein (POC: Dr. Kathryn Taylor, USARIEM) indicated that the use of NSAIDs was associated with a 2-fold increased risk of stress fracture in the entire Army population. Further, there was nearly a 5-fold increased risk of stress fracture during initial military training time period, a time when anabolic bone formation should be active.

These results served to fuel a collaborative and multi-level investigation into NSAIDs, from *in vitro* cellular studies to further population-level studies within the military performance division and with collaborators at Boston University and Thomas Jefferson University. Some of the questions investigators hope to answer relate to identifying dose-response relationships and potential analgesic substitutes, with the overall goal of providing evidence-based guidance to Army clinicians for NSAID prescription, particularly during times of high risk for stress fracture.

The second End State Goal of this topic area is to optimize and enhance musculoskeletal health and performance. In order to achieve this end state, it is important to leverage how responsive musculoskeletal tissues are to their environments. An example comes from a case study published in the 1960s, where a man had an above-the-knee amputation earlier in life. Instead of using an assistive device, he hopped around on his intact leg for most of his life, wherein the mechanical loading resulted in very dense and thick cortices in the non-amputated leg, while the cortices were thin and porous in the amputated limb. This helps demonstrate that bones are mechanosensitive, as are other musculoskeletal tissues. Therefore, we can exploit the plastic nature of these tissues to maximizing musculoskeletal health and performance.

While the notion that bone is mechanoresponsive has been around for a long time, the technology to capture mechanoadaptive responses in humans has only recently emerged. This lack of noninvasive bone imaging technology has led to an ongoing debate as to the ability of exercise to make bones stronger in humans. USARIEM has been an early adopter of new, high resolution bone scanning technology, which have been employed in the ARMI study and in one of its predecessor studies. This technology has the voxel resolution of 61 microns, which is less than the width of a human hair and allows us to peer into the microstructure of the bone and see how it changes with military training.

This imaging technology has allowed scientists to see how initial military training impacts bones. For example, the bone at the distal site is largely trabecular, or spongy bone, and the trabecular elements are a fair amount thicker in this recruit after only 8 weeks of training. The 3-D capability shows where new bone has been added. Altogether, this provides evidence that physical exercise does make bones stronger, similar to the way that muscles get stronger with exercise.

With regard to risk factors related to optimal bone formation, it has been dogma for decades that anabolic bone formation only occurs in the growing skeleton. Data from the ARMI Study has debunked that myth. In this analysis, scientists looked at the bone response to BCT in trainees at the very end of the growth spurt (i.e., 17 to 19 year olds), relative to those who were very likely entirely done growing and accruing adolescent bone mineral accrual (i.e., > 20 years of age and older). The older trainees mounted an anabolic response to training, like the younger trainees, although this response was slightly muted. These results have provided some of the most convincing evidence that bones are responsive to exercise, even in the adult skeleton.

After establishing that this adaptive bone formation does indeed occur, the next step is to study the different factors that promote or inhibit this formation response in order to determine the best solutions to optimize and enhance bone strength. These investigations require collaborating with many different scientists in military science and academia and would require more than a lifetime's worth of research. Hence, scientists at USARIEM are building an ever-expanding coalition of researchers who can help solve the problem of stress fracture and promote bone health and performance in Warfighters. These efforts are intentionally aimed at providing the scientific research needed to build strong bones to ensure strategic advantages and overmatch in the future operational environment.

Building on the research that indicates that bones are mechanosensitive, results from the ARMI Study also indicate demonstrate positive changes in muscle and lean body mass during basic training. For example, while body mass changes very little, especially in women, only eight weeks of training resulted in average increases of five pounds of lean body mass and loss of about 5 pounds of body fat, resulting in a total change towards a healthier body composition profile of 10 pounds throughout BCT. Next steps are to determine how we can best promote this healthy change in all trainees and to determine the relationship between these changes and injury risk.

Building on the MSKI work, it is also important to consider how the musculoskeletal system will interact with the environment in the FOE. Prior LOE1-focused workshops have discussed biomarkers and real-time physiological monitoring. With regard to interpreting circulating biochemical markers, one of the many challenges is how to interpret what the biomarkers are really reflecting and what the consequences of the changes are to health and performance. For example, the biological response of bone to changes in the mechanical environment gives us a good example of these challenges. At the cellular level, bone formation and resorption can respond to situations of increased and decreased mechanical loading. The responses of bone vary for different reasons, and the resultant adaptations can take weeks, to months, and even years to be completed. Real-time physiological monitoring of skeletal responses to military operational activities therefore requires a strong understanding of the varying physiological responses of bone to operationalize the efforts. For example, circulating biochemical markers of bone formation declined during rigorous US Army Ranger training. Despite the complex physiological responses of bone to exercise, any period of heightened physical training like that experienced by Ranger trainees, should result in anabolic bone formation. Decreases in bone formation are therefore concerning and can reflect any number of stressors experienced during this type of elite military training, to include, changes in energy and micronutrient availability, psychological stress, poor sleep, use of NSAIDs, and many more. Biomarker use and solutions for optimizing musculoskeletal health and performance in the future operational environment are going to require multidisciplinary subject matter expertise and collaborations.

Panel discussion

As with prior LOE1-focused workshops, attendees continued to indicate that it was helpful to consider their research efforts in the context of the realistic situation presented in the vignette. Observations from the panel discussion regarding the vignette itself, and integration of the vignette into capability development, follow.

In addition to previous observations (Appendix 2), it was noted that there were other potential MSKI risks associated with poor posture (in addition to a sore neck). In terms of general lack of trust and cohesion, it was noted that psychosocial metrics increase risk of injury. Stress (e.g., anger illustrated by the protagonist) repeatedly can impact bone formation and related processes, as does inadequate sleep quality/quantity and

inadequate energy intake. Further, multiple stressors over long period of time increase MSKI risk. In terms of status tracking, long term (months/year) data from status trackers can be helpful to determine injury risk, since chronic conditions may accumulate over time.

During the panel discussion, the following topics were addressed:

The MSK system is not just an inert structure, i.e., it's very much alive and tissues go through remodeling, for example. As research emerges regarding the physiology of these tissues, it is apparent that we need to be good stewards of our MSK system. It takes a fair amount of exercise to optimize the MSK system and requires consideration of stressors in the environment that may, over time, break down and put the MSK system at risk for injury. When we consider the concept of "Soldiers for life", it's important to consider the influence of training and operations on MSK health later on in life, e.g., in some ways there can be negative consequences, but in other ways an active lifestyle may be protective (e.g., osteoporosis and sarcopenia).

Given the amount of combined stressors that Soldiers face in the extreme training and operational environments, there is some notion that much of our natural stress response is to shut down a host of physiological pathways. Conversely, however, it's a protection mechanism and countermeasure to stress, allowing the body to use energy for other necessary physiological functions. There are ways that we can alter the training and operational environment in practical ways, without negatively impacting Soldier effectiveness, to allow adaptations to optimize health and performance. For example, maximizing the quality of sleep when quantity is inadequate and developing; testing interventions to assist muscle adaptation to intense, prolonged training; and, implementing nutrition interventions to preserve muscle wasting and prevent bone loss.

When we talk about performance enhancements targeted to muscle performance, there are some key S&T focus areas for consideration, while also considering potential acute or downstream negative side effects of those enhancements. For example, assisted devices offer ways to offload stress to reduce MSKI and could be advantageous for preventing injury. However, if we don't have the opportunity to develop the mechanical adaptation (or a healthy adaptive response), it could increase the risk of MSKI, i.e., exoskeletons and other ways to offload the soldier may be helpful, but stimulation is necessary to build a healthy adaptive response. Additionally, there are ways to promote muscle anabolism and enhance musculoskeletal function and physical performance. Three examples include: 1) Nutritional and nutraceuticals strategies to enhance physical performance; 2) Enhancement of muscle output by neuropriming with transcranial electrical stimulation (tES); and, 3) developing a musculoskeletal anabolic agent that can safely and ethically enhance muscle, bone, cartilage, tendon and ligament strength and performance such that our Soldiers and teams have a physical performance advantage over adversaries.

There was also some discussion of what we are trying to optimize and enhance. Optimization refers to reaching the maximum of what we are inherently capable of achieving, while enhancing refers to going above and beyond our inherent capabilities. Therefore, it's important to discuss enhancement strategies and outcomes in the context of what will benefit Soldiers (e.g., considering measures of performance and measures of effectiveness). For example, when we build muscle there's a metabolic cost associated with it wherein bones need to adapt to mechanical loading of additional muscle and other systems are impacted by that additional muscle. Similarly, when we build bone tissue, there's a metabolic cost and it takes more supporting tissue to move that bone. Therefore, the goal is to build the most efficient Soldiers, maximizing the MSK system to perform the required tasks, not to necessarily develop the biggest muscles (or the strongest bones).

Additional questions for future discussions:

- How can other SME help advance MSK health and performance?
- Can improved MSK health and performance add to your S&T focus and goals?

Approaches to optimize and enhance all aspects of performance when exposed to environmental extremes/conditions and hazards

March 7, 2022

This session was moderated by Dr. Tracey Smith (Lead, LOE1).

Broad S&T and Cross Adaptation (Dr. Roy Salgado, USARIEM)

This session focused on operational challenges at altitude, science and technology gaps and ongoing or upcoming high altitude research initiatives, to include those using pharmacological countermeasures and cross-adaptation strategies. In terms of future operational environments, there are many areas with elevations greater than ~2,500 m (e.g., North Korea, Pakistan, India and China) as well as high mountainous terrains in Russia and the surrounding areas. Some mountainous regions also have high temperatures which speaks to the combination of environmental stressors, which pose a greater risk to Warfighters compared to a single stressor environment.

There are operational challenges at high altitude, to include decrements in physical (endurance) performance, acute mountain sickness, sleep disturbances, delayed wound healing, and decrements in cognitive function. For example, a 2 mile run at sea level that takes ~20 minutes will take ~25 minutes at an altitude of 3,500 m (i.e., ~28% decrement) and ~31 min at an altitude of 4,300 m (i.e., ~55% decrement). Acute mountain sickness (AMS) also occurs at high altitude (probability 20-80%), and rapid ascent to altitudes > 2,400 m increases probability. This can be debilitating, with symptoms such as: headache, dizziness, lightheadedness, fatigue, shortness of breath, nausea, vomiting, and facial swelling. Additionally, sleep disturbances can occur secondary to high altitudes greater than 1,500 m. Periodic or Cheyne-stokes breathing (3,000 m) leads to hypoxemia during sleep; and, sleep restriction negatively impacts Warfighter function during waking hours, including fatigue, cognitive deficits and mood disturbances. In addition to the aforementioned physiological and cognitive declines, delayed wound healing also occurs in response to altitude exposure secondary to sleep restriction.

Decrements in cognitive dysfunction (e.g., degraded memory and reaction time), independent or concomitant with sleep restriction, occurs with altitude exposure. Additionally, dismounted Soldiers are also carrying loads in excess of 30% of their body weight over rough terrains, which may increase musculoskeletal injury risk. Additionally, appetite changes occur at high altitude, thus compromising nutritional intake and performance decrements associated with inadequate intake. Other environmental influences occur at altitude, to include colder temperatures that increase with altitude, while other areas have very hot temperatures at altitudes. This combination of stressors pose a greater risk to Warfighters health and performance compared to a single stressor environment.

Existing science and technology gaps in this topic area include:

- Countermeasures for mitigating altitude-induced decrements in endurance performance. For example, the most effective means to better tolerate high altitude is gradual acclimatization to HA; however, that is logistically difficult (takes days to weeks), so it's important to consider other countermeasures that can be used to mitigate performance decrements [or maximize human performance] in response to high altitude.
- Mechanism of AMS- unacclimatized individuals experience AMS, but the exact mechanism hasn't been fully elucidated.
- Prevention of AMS, e.g., with Acetazolamide (or other pharmaceuticals) and/or training practices. Acetazolamide is the only FDA-approved drug, but it's contraindicated for individuals with allergies to the drug components, thus additional pharmacological interventions are warranted.
- Risk factor identification for predicting AMS; and, predictors for AMS and performance decrements.
- Inter-individual responses to altitude, in general; and, the reasons for these individualized responses are unclear.
- Deacclimatization (i.e., loss of physiological adaptations that have been helpful for high altitude) is elusive and there's no strategy to maintain acclimatization and reduce deacclimatization and/or speed up reacclimatization.
- Low / Moderate altitude residents, e.g., are the countermeasures for those at sea level the same as those for those that reside at moderate altitude environments?
- Proper nutrition – body weight & muscle mass loss / high altitude anorexia. Negative energy balance and loss of muscle mass is an issue.

High Altitude Research Initiatives

The problem (performance decrements and AMS) occurs from high altitude on one end of the pendulum and countermeasures (pharmacological and cross-adaptation) to maximize human performance on the other end of the pendulum. These initiatives are addressing interventions to mitigate performance decrements and AMS; and, to maximize human performance while at altitude.

Figure 24 shows details regarding a study that is testing the efficacy of a pharmacological countermeasure. The rationale is that altitude exposure causes physical performance degradation and increases the incidence of acute mountain sickness. Acetazolamide increases ventilation and promotes ventilator acclimatization; however, performance is still degraded. However, the study is testing the combination of acetazolamide with erythropoietin (increases red blood cell count) as countermeasures to mitigate performance decrements secondary to AMS. A deliverable of the study is a validated countermeasure to mitigate performance decrements and prevent/reduce AMS during exposure to altitude.

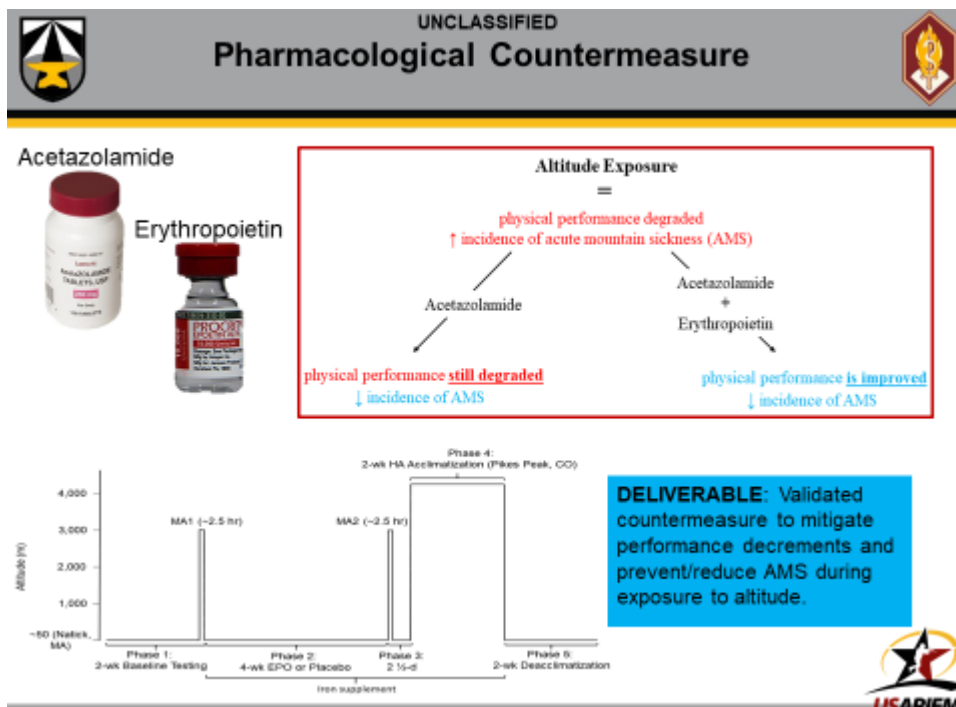


Figure 24. Pharmacological Countermeasures

Another current effort using pharmacological interventions is determining the efficacy of intravenous iron prophylaxis to mitigate impairments in oxygen saturation and endurance performance in acute hypobaric hypoxia, i.e., to attenuate cognitive and endurance performance degradations. The IV iron can be given 1-2 days before persons travel to high altitude and the effects can last for ~6 weeks, which is highly desirable for our military population performing in this environment. A deliverable from this study is a translational countermeasure to improve Warfighter physical performance during rapid high altitude insertions.

Another intervention to mitigate performance decrements at high altitude is cross-adaptation. Continuous or repeated exposure to a given environmental stressor (heat, cold, or high altitude) induces physiological adaptations that allow humans to better tolerate a particular environment. Cross-adaptation is phenomenon where physiological adaptations induced by one environment stressor (hot) that may have benefits when exposed to a completely different environment (altitude). In the future operational environment, stressors are experienced in series or combination, e.g., deploy to hot areas and then travel to altitude and cold and altitude often go hand-in-hand. The practical benefits of cross-adaptation is that it provides “protection” against two environments.

Prior work using cross-adaptation to mitigate performance decrements has studied heat acclimation in between two separate hypobaric hypoxia exposures to increase endurance performance and reduce AMS (*Cite Salgado et al., Effect of 8 days of exercise-heat acclimation on aerobic exercise performance of men in hypobaric hypoxia, AJP-Regulatory, Integrative and Comparative Physiology, 2020*). While the heat acclimation intervention did not alter endurance performance, heat acclimation did reduce the incidence of AMS during the second hypobaric hypoxia exposure. This demonstrated a potential benefit of cross adaptation practices and further research is needed. Another cross adaptation method uses cold adaptation to mitigate decrements in physical performance and acute mountain sickness during altitude exposure. Prior exploratory research has demonstrated positive benefits of cold habituation on physiological strain and AMS symptoms. Ongoing work

is determining if cold habituation can reduce physiological strain (cardiovascular, respiratory, sympathetic nervous system), improve performance, and decrease incidence/severity of AMS. This work is ongoing and, if effective, will deliver a simple countermeasure to improve performance and reduce incidence and severity of AMS during mountain operations.

Work in this area informs Army doctrine. For example, Technical Bulletin Medicine (TB MED) 505 addresses altitude acclimatization and illness management addresses physiological responses, adaptations to altitude, physical performance capabilities at altitude and altitude risk management. As we consider the future operational environment of 2030 and 2040, and the S&T necessary to optimize and enhance human performance, it is critical to recognize the combined stressors of mountain environments, to include heat, nutrition, sleep, cold and mountain sickness that impact Warfighter health, readiness and performance.

Human Performance Optimization in Artic environment (Dr. John Castellani, USARIEM)

Overview

This portion of the workshop addressed cold weather research and development initiatives, particularly at USARIEM. Operational challenges in this topic area include:

- The selection of proper clothing and when to change clothing based on mission and environmental conditions. For example, management of moisture accumulation in cold-weather clothing. Additionally, clothing mass increases energy expenditure.
- Loss of hand and finger function during cold-weather operations (e.g., weapons, use of digital devices, IV placement). Additionally, gloves decrease dexterity by 60-70%.
- Proper nutrition and hydration. E.g., there is extensive evidence that Soldiers do not eat enough and are dehydrated during cold weather exposure.
- Predicting when Soldiers will get a cold injury and determining which Soldiers are at higher risk of cold injuries.

The overarching goal of research in this area is to enhance Soldier performance & medical treatment in the cold, to optimize performance and achieve overmatch. Science and technology gaps that must be overcome include:

- Cold-wet exposure physiology and thermal modeling
- Immersion guidance
- Minimal power requirements for auxiliary heating & dexterity maintenance
- Wearable sensors for mission planning and risk assessment
- Protective clothing for multi-environmental conditions
- Mechanisms of habituation/improved thermal toughness
- Mechanisms of peripheral blood flow
- Post cold injury return to duty criteria
- Risk factor identification
- Water availability
- Energy intake to match energy required
- Medical treatment (equipment)
- Medical treatment (algorithms)

USARIEM cold weather research initiatives include injury prevention guidance (e.g., cold-wet, water immersion (Figure 25); clothing requirements; peripheral sensors; and, guidance documents); maximizing human performance during cold exposure via countermeasures for dexterity and foot function; and, nutrition interventions to promote performance during, and recovery from, cold exposure.

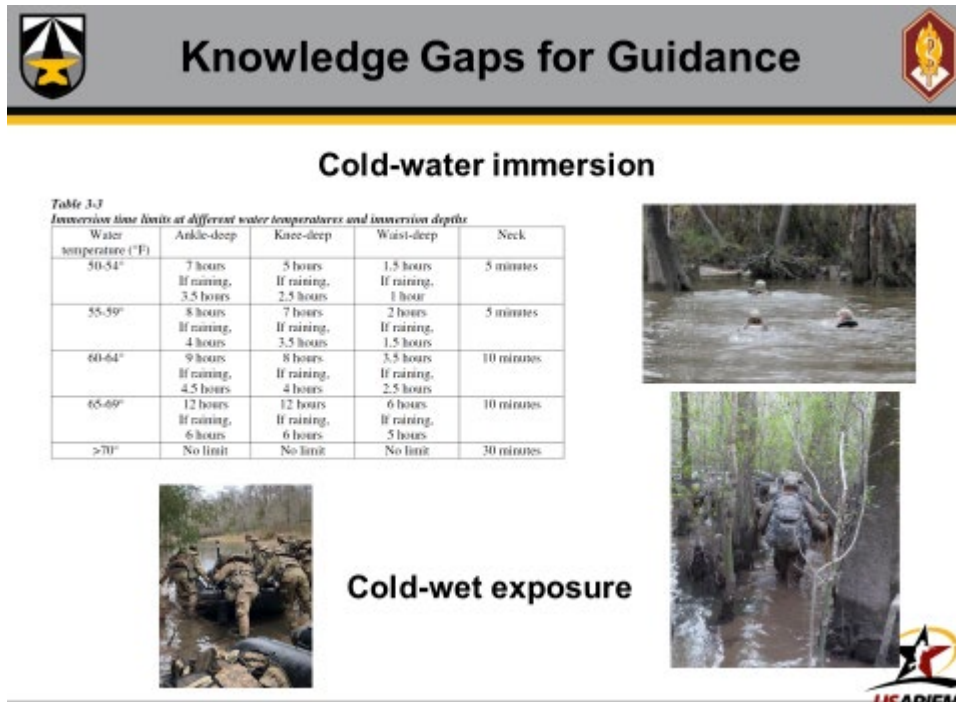


Figure 25. Cold-wet, water immersion

Clothing decision aids include quantitative guidance for evaluation & comparison of thermal performance provided by cold weather ensembles. The Cold Weather Ensemble Decision Aid (CoWEDA, Figure 26) considers the mission (e.g., duration and activity) and environmental conditions (e.g., temperatures, humidity and wind speed) to determine the clothing requirement (i.e., what clothing configuration is needed to prevent hypothermia and frostbite). This decision aid also determines planning parameters, i.e., what clothing is available and what is the time duration until hypothermia or frostbite becomes an issue. Potential users of CoWEDA are mission planners, materiel developers, and uniform acquisition officers.

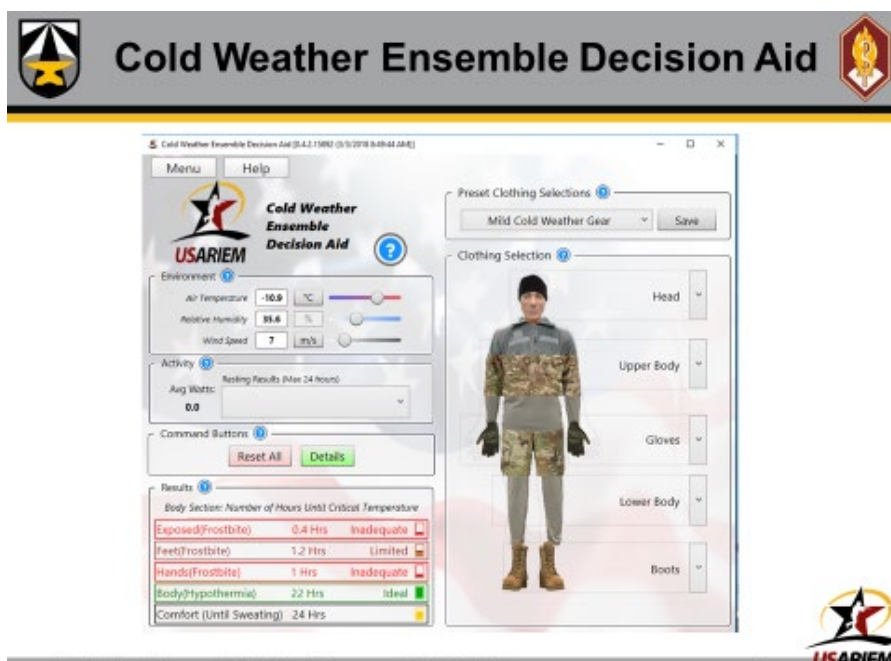


Figure 26. Cold Weather Decision Aid (CoWEDA)

There is also ongoing work in the area of cutting edge thermal modeling. The COWEDA model is based on a model that was developed many years ago, based on six areas of the body. Current efforts are considering finite element analysis, which allows these thermoregulatory models to be run on any point on the body. By using discrete, anatomically and geometrically correct human meshes, one can predict what the temperature is in any region of the body with increased accuracy and resolution (e.g., finger temperature, whereas the prior model can only predict hand temperature which may be significantly different).

Another area of ongoing work involves the use of peripheral temperature sensors. It is challenging to accurately measure peripheral body temperature and older methods are logistically cumbersome and do not provide real-time information. In contrast, there is ongoing research and development of new field-expedient measurement technologies (real-time) for temperature assessment and frostbite detection. For example, proof of concept was recently tested and validated at Operation Arctic Eagle/Patriot 2022 using a wireless signal; and, follow-on efforts are planned.

The cold negatively impacts dexterity and strength making it difficult for Soldiers to perform tasks in the training and operational environment. Focused heating to improve dexterity is a solution to improve temperature in the extremities and subsequently dexterity and strength. Scientists at USARIEM are working to develop a personal heating dexterity device. This effort started with a proof of concept controlled laboratory study, wherein the forearm was down-selected as the optimal site for heating and resulted in a 3°C increase in the fingers and hand with 50% improved dexterity and 90% improved finger strength. A prototype design development path is underway with USAMMDA (Warfighter Health, Performance and Evacuation) and SBIR efforts. The latter has progressed from three phase 1 prototypes to a phase 2 award developing novel material, novel power sources, novel heating sources and a layered approach to commercialize the design. Deliverables for a field-validated peripheral heating dexterity device (PHD2) include a low-energy, lightweight, low-profile and form-fitting design, resulting in a 8 degree Celsius increase in the fingers and hand with 75% improved dexterity and 90% improved finger strength.

In addition to a personal heating dexterity device, there may be countermeasures that can increase peripheral blood flow and overcome the effects of cold-induced vasoconstriction for dexterity improvement and foot function. Bioflavanols (antioxidants) were tested, but not successful. Cold habituation, ischemic pre-conditional, and calf warming are all areas of further study.

Nutritional strategies are also being studied for muscle recovery and repair during cold weather training. The purpose of this work is to determine the physiological efficacy and acceptability of essential amino acid (EAA)-enhanced and energy density-enhanced combat ration products during 7 days of winter military training. Efforts have previously determined the optimal protein dose; determined optimal protein composition; and, determined optimal energy substrate to accompany protein content. A recently completed study (March 2022) tested the field efficacy and acceptability of prototype protein-centric and energy dense ration products during a Norwegian winter training exercise and analyses is ongoing.

Work in this area informs Army doctrine. For example, TB MED 508 addresses the prevention and management of cold weather injuries (Department of the Army, 2005). This guidance addresses physiological responses, hypothermia prevention, frostbite prevention, NFCl prevention, food & fluid intake and medical treatment. This guidance document is currently under revision and includes representatives from OTSG, USARAK, TRADOC, DEVCOM, SOCOM, APHC, NWTC, 6th RTB, 10th Mountain, AKNG, et al.

Defense Health Program (JPC-5), Human Performance Optimization in Extreme Environments

Current efforts within this topic area, that are funded via the Defense Health Program, include: 1) Predicting Mission Impact in Extreme Environments: Effect of Cold Climates and CBRN PPE on Human Performance; 2) Combat Marksmanship in Extremely Cold Environments: Assessing Impacts on Cognitive Functions and Developing Data-Driven Counter-Measures; 3) Individualized Thermoregulation Models for Soldier Lethality Simulation. Future objectives include: 1) The design of new, or significantly improved, methods to prevent, detect, and treat frostbite injuries; 2) methods/countermeasures to prevent, monitor, and oppose performance decrements induced by hypothermia; and, 3) guidance for work/rest cycles during training and operations in the Arctic.

Panel discussion

As with prior LOE1-focused workshops, attendees continued to indicate that it was helpful to consider their research efforts in the context of the realistic situation presented in the vignette. For this workshop, it was particularly helpful to consider the scenario in the context of environmental extremes, e.g., cold exposure as indicated in the scenario. There were no additional observations from the vignette, nor additional considerations to make the vignette more realistic or useful, beyond what has been previously discussed (i.e., summarized herein and in Appendix C). Observations from the panel discussion regarding integration of the vignette into capability development, follow.

There are geopolitical and environmental factors that might drive demands of this research in the context of the FOE2040. For example, as climate changes and as oceans open up (especially in the North, both the northwest and northern passage), there will be a greater human presence in these regions due to commercial activity, energy security, and natural resources, all potentially impacting national and regional security. These will be a driver for future research efforts in this area.

The differing nutritional needs in the Arctic environments compared to temperate environments and the potential for physiological changes that drive macronutrient needs was discussed. There is some evidence to suggest that energy requirements are higher in the cold, secondary to the metabolic cost of performing tasks in this environment (e.g., difficulty traversing winter terrain and clothing and equipment burden), in addition to the maintenance of body temperature. This increase in energy needs is complicated by inadequate energy intake that has been documented. Thus, encouraging energy intake to mitigate energy deficit and body weight loss, and subsequent performance decrements, is paramount. Macronutrient utilization does not appear to be different in cold, compared to temperate, environments, as long as proper clothing is maintained (e.g., when clothing is inadequate and shivering ensues, carbohydrate oxidation increases during exercise. With that said, when energy deficit is unavoidable, provision of essential amino acids may mitigate performance decrements during cold exposure and energy dense rations may be beneficial to maximize energy intake (e.g., data analyses is ongoing).

The topic of respiratory tract infections also arose. The FOE conditions include rapid oscillation in temperature extremes due to climate change which are expected to precipitate physiological and psychological stress. This stress may subsequently cause immune decrements, thus increasing infection risk (e.g., respiratory, gastrointestinal, skin and soft tissue infections, etc...).

Specifically regarding the vignette, and the related cold exposure, we can consider innovative materiel protection measures that were discussed today. If current, near-term, efforts are successful (e.g., personal heating dexterity devices and peripheral temperature sensors), more advanced, high-tech options may be achievable, e.g., a thermal protection suit. Developing a tight-fitting, full-body, lightweight thermal protection suit that both dissipates and provides heat during hot and cold-weather operations, respectively, would enhance Soldier performance and mitigate injury during missions in all weather conditions. Additionally, power supply on the nanotech level to operate the suit would be necessary.

Interventions (e.g., pharmacological, nutritional, synthetic biology, etc...) and strategies (e.g., training) to optimize health and enhance physical performance

March 21, 2022

Pharmacological Approaches (Dr. Lee Margolis, USARIEM)

The work presented today is a key part of the Biomedical Performance Enhancement strategic plan, with the goal of optimizing individual soldier physical and non-physical performance and individualized health and physical readiness. This work specifically addresses technical objectives related to materiel solutions (pharmacological & technological) that enhance Soldier physical performance and/or enhance Soldier resistance to environmental stressors

Military operations result in high daily energy expenditures, ranging from 3500 – 7000 kcal/d subsequent to sustained physical activity (e.g., multiple patrols per day, traveling long distance) and carrying heavy equipment (25 -50 kg) and environmental exposure. This is coupled with suboptimal energy intake during military operations, secondary to limited food availability, mission requirements curtailing time to eat, lack of desire to carry extra weight, and, lack of desire to eat.

When energy needs are not met during military operations, muscle glycogen (i.e., the storage form of glucose) content is reduced by as much as 50% following military operations. This reduces the amount of glycogen available to fuel muscles, but also increases IL-6 transcription in muscle which results in increased circulating concentrations of IL-6 and an increase in inflammation. The downstream consequences are sequestration of iron, decreased red blood cell production, declining levels of hemoglobin and hematocrit levels, which ultimately degrades oxygen carrying capacity and compromises physical performance.

Efforts within this topic area leverages performance enhancing drugs to increase Soldier lethality.

Erythropoietin (EPO), for example, is a hormone produced in the kidneys to stimulate production of red blood cells and also may have other benefits, e.g., increases mitochondria in skeletal muscle and increases reliance on fat stores for fuel, thus sparing glycogen which is the body's preferential fuel source. Exogenous EPO has been used as a performance enhancing drug. However, it remains unclear if exogenous EPO can effectively combat negative physiological effects experienced by Soldiers to enhance their physical performance.

Current work seeks to determine the effects of EPO on hematological adaptations and physical performance compared to placebo (PLA; saline) during 4 weeks of overtraining. This study is also assessing the influence of EPO on non-hematological adaptation (e.g., whole-body and skeletal muscle substrate oxidation) following 4 weeks of overtraining compared to PLA. The main outcome measures are substrate metabolism and performance tests. Physical Performance Tests include a 5 km treadmill run 5 times during the study. Substrate metabolism (i.e., how the body uses fuel) is measured in response to 90 minutes of load carriage (30% body mass) treadmill exercise via indirect calorimetry, stable isotope tracers (continuous infusion of 6,6-D₂-glucose stable isotope); and, muscle biopsies.

Additional efforts are focused on mitigating physical performance decrements during high altitude operations. Deployments to austere and remote high altitude (i.e., hypobaric hypoxia) mountainous regions will occur during Multi-Domain Operations [refer to 7 March 2022 workshop discussed herein]. A fall in atmospheric pressure with altitude decreases the partial pressure of oxygen (PO₂), limiting oxygen delivery to tissues. Rapid ascent to high altitude (i.e., hypobaric hypoxia) elicits physiologic and metabolic adjustments that collectively

degrade physical performance and augment dietary requirements. Reductions in PO_2 makes carbohydrate the most efficient fuel to sustain performance at high altitude. Oxidation of carbohydrate is increased and fat is decreased in native lowlanders performing metabolically-matched, steady state aerobic exercise during acute high altitude exposure compared to sea level.

Even though the body requires greater amounts of glucose during acute exposure to high altitude, there is evidence that exogenous glucose oxidation was ~30% lower with metabolically matched absolute exercise intensity during acute (< 8 hrs) high altitude exposure compared to Sea Level. This demonstrates a reduced efficiency in exogenous glucose oxidation during high altitude conditions. In other words, while the muscle is taking up and using less glucose for fuel during high altitude, a carbohydrate supplement isn't used as efficiently as fuel (compared glycogen stores). This seems to be a function of hypoxia induced insulin resistance (Figure 27). When participants are provided with glucose before and during steady state exercise, there are greater increases in circulation glucose and insulin concentrations during exposure to high altitude compared to sea level conditions. Reductions in exogenous glucose oxidation (panel A) was associated with reductions in glucose rate of disappearance (panel C) and metabolic clearance rate (panel D). Altogether, even though there's more glucose in circulation, the body is using less of it.

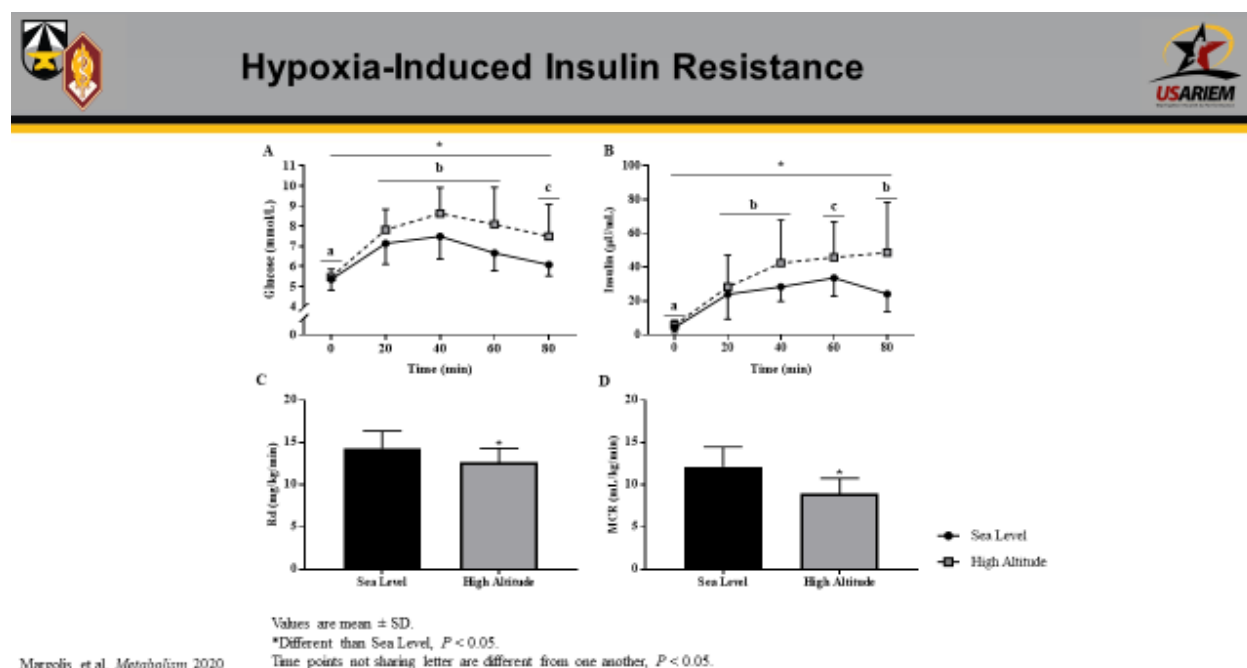


Figure 27. Hypoxia-induced insulin resistance

In order to address the reduced efficiency of substrate oxidation (i.e., fuel use) during high altitude conditions, an upcoming effort will determine the effects of an oral diabetes medication (Pioglitazone or PIO) on hypoxia-induced insulin resistance and subsequent exogenous glucose oxidation and glucose turnover during exercise under acute HA exposure compared to placebo (PLA). Pioglitazone (PIO) is a thiazolidinedione (TZD) medication that acts as a ligand to activate peroxisome proliferator-activated receptor- γ (PPAR- γ). PPAR- γ increases insulin sensitivity and glucose uptake in peripheral tissue and may also reduce inflammation and lipid accumulation.

In summary, arduous military operations results in physiological consequences that may require robust interventions to negate. Pharmacologic interventions may be warranted for specific operational conditions to optimized or enhance physical performance. USARIEM is currently engaging in a series of investigations assessing the effective of pharmacological interventions in various operational conditions.

Gut microbiome manipulation for human performance optimization (Dr. J. Philip Karl, USARIEM)

This presentation addressed how the gut microbiome can optimize physical performance, current efforts and future research directions. The human microbiome is vast and genetically diverse. There are approximately the same number of bacterial cells to human cells. However, there are actually more microbial genes than human genes on and in the human body, and those microbial genes carry out a variety of functions that human genes cannot.

The gut microbiome is a malleable genomic reservoir influencing physiology. There are various factors that impact the gut microbiome, including diet, physical activity, acute and chronic stress, medications, circadian rhythm and environmental characteristics (e.g., high altitude, heat, cold). These factors impact how the gut microbiome modulates the immune system, enteric nervous system and metabolite production (e.g., paracrine & endocrine effects), which subsequently effects functions throughout the body including: cognition, mood, behavior, cardiovascular function, immunity/inflammation, pathogen resistance, energy metabolism, substrate metabolism, nutrient absorption, oxidative stress, intestinal barrier function, muscle repair/recovery and bone health.

The gut microbiome is a new target for military performance optimization. Warfighters are exposed to operational stressors and changes in diet intake (e.g., unaccustomed food, inadequate energy intake, lack of fresh fruit and vegetables in certain operational scenarios) that impact the microbiome, and ultimately health, readiness and performance.

There are multiple potential applications for the gut microbiome as a performance enabler, e.g., in the context of predicting, differentiating and personalizing interventions; modulating cognition and behavior, and stress responses; impacting physical performance including providing a source of novel ergogenics (e.g., glucose metabolism); and, use in novel diagnostics and therapeutics related to health and readiness (e.g., engineering microbes) (Figure 28). Today's session focuses on the latter two topics.

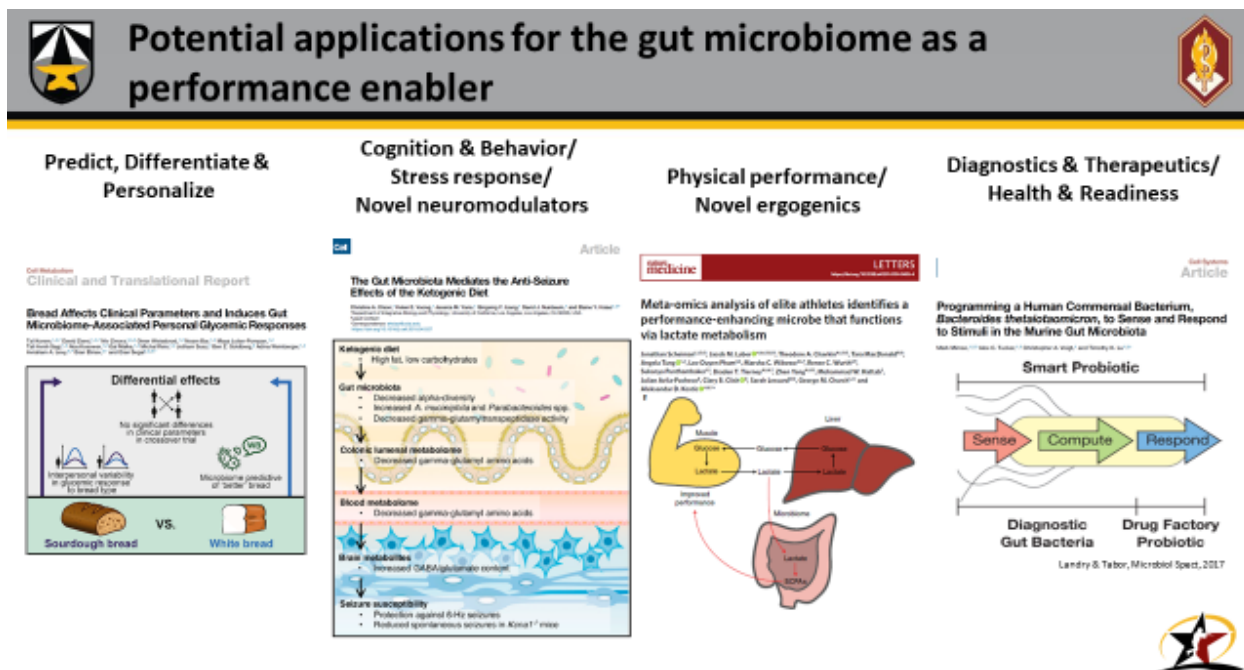


Figure 28. Potential applications for the gut microbiome as a performance enabler

One example of how the microbiome can be mined to novel ergogenics derives from a study in which a microbe isolated from elite athletes improved aerobic endurance when fed to mice. Data from that study indicated that the performance-enhancing microbe converted lactic acid produced during exercise to short chain fatty acids, which that can be used as an energy source. Further research is necessary to determine whether this pre-clinical, proof-of-concept type evidence translates to the clinical setting and military personnel.

There are other potential mechanisms for gut microbiome modulation of physical performance. The possible mechanisms include altering antioxidant enzyme activity, modulating the immune system, gastrointestinal permeability, utilization and storage of metabolic substrates, cross-talk of cell components where respiration and energy production occur, and the gut-brain axis (Hughes RL, 2020).

Current efforts at USARIEM are focusing on harnessing the microbiome to optimize performance. For example, an ongoing project in collaboration with DEVCOM-Soldier Center is studying nutrition-based manipulation of the gut microbiome for performance optimization at altitude. The purpose of the study is to determine if a novel gut microbiome-targeted nutrition intervention can improve gut health and cognitive performance at high altitude. Main outcomes are cognitive-based, but this model may also be applied to physical performance outcomes.

An upcoming effort (FY22-24) is attempting to harness microbiota-derived metabolites to improve endurance performance. This study has two aims: to determine the effects of increasing colonic short-chain fatty acids (SCFA) on aerobic endurance; and, to determine the effects of increasing colonic SCFA on substrate oxidation during exercise, muscle glycogen, and intestinal permeability. This study is based on evidence that certain gut microbes may use lactic acid to produce SCFA; and, hypothesizes that increasing colonic SCFA will improve endurance performance by increasing muscle glycogen content, and energy availability and glucose metabolism during exercise, and by decreasing inflammation, gut distress and intestinal permeability.

Other studies will focus on the concept of performance probiotics; i.e. feeding live beneficial microbes to improve physical performance. In the context of performance probiotics, existing evidence suggests that certain bacterial strains may induce physiological changes that could offer physical and/or cognitive health and/or performance benefits to military personnel. However, physiologic changes do not necessarily translate into performance effects, and there are many gaps in the evidence base (Agans et al, *Frontiers in Nutrition*, 2020). Therefore, at present, there is not compelling scientific evidence to support the use of any particular probiotic(s) for physical or cognitive performance optimization in military personnel. However, two upcoming efforts will assess the efficacy of probiotics for physical performance optimization. The first will determine if consuming probiotics reduces exercise-induced muscle damage or improves physical endurance; and, the second study will determine if probiotics that enhance endurance performance in mice have the same effect in military personnel.

Other efforts are attempting to develop engineered next-generation probiotics for various functions including physical performance optimization. This is ongoing work by Air Force Research Lab and other DoD organizations (e.g., Nelson 2021). As one example of potential applications, ongoing efforts are attempting to engineer microbes to sense physiologic indicators of inflammation or stress, and then respond by upregulating production of a molecule that can attenuate that inflammation or stress.

Deliverables for the Army of 2030 and 2040 include microbiome-targeted nutrition solutions for improved physical/mental preparedness and performance optimization (near-term); prediction of susceptibility/resilience and precision interventions (mid-term); and, engineered microbiomes for monitoring/diagnosis and sensing/responding (far-term).

However, manipulating the microbiome to optimize and enhance physical performance is a nascent field with needs and gaps that need to be overcome to realize these deliverables. Further research is necessary to elucidate what microbes to target and how, which will require further observational studies; better understanding of microbial genomes; translating promising results from pre-clinical models to human models; improving measurement techniques (e.g., current reliance on fecal samples which isn't representative of the entire gastrointestinal tract); collecting and integrating big data (e.g., large volume of data makes it difficult to extract actionable information); inter-individual variability (e.g., make it more difficult to see group differences but potentially easier to develop personalized strategies); safety (e.g., developing engineered microbiomes requires careful attention to safety); and, thinking beyond the gut and beyond bacteria (e.g., considering other microbiomes on the body and in the environment and leveraging those to improve human performance).

Fatigue management (Dr. Tina Burke, WRAIR)

The Behavioral Biology Branch at WRAIR seeks to develop interventions and technologies to mitigate the effects of fatigue, increase resilience to traumatic stress, and promote performance in Soldiers. This branch includes the following sub-sections: Performance Assessment and Chemical Evaluation (PACE; pre-clinical work); Sleep Research Center (SRC; clinical-setting); and, Operational Research Team (ORT; field application).

Work within the SRC is based on the threat of sleep disturbance, wherein sleep can make the difference between mission success or failure; and, sleep loss is often unavoidable in deployed environments. Approximately 65% of Soldiers are chronically sleep deprived (<7 hours of sleep per night); 51% of accidents in deployed settings are attributable to sleepiness; and, 25% of motor vehicle accidents are attributable to sleep deprivation. Inadequate sleep is associated with declines in performance, recovery, health and an increase in

injury. Current work seeks to determine how fatigue may be managed during continuous and sustained military operations.

Known, evidence-based Warfighter fatigue management strategies include sleep management planning, sleep banking, tactical naps, caffeine and mindfulness. The Behavioral Biology Branch has produced a number of fatigue management products. Resources are focused on a specific unit or stakeholder, in some cases that have requested assistance. For example, one infographic offers fatigue management guidance during nocturnal operations. Another quick guide provides strategies to manage sleep under stressful conditions. Another reference addresses caffeine, sleep and performance in the operational environment, while another infographic addresses tactical napping.

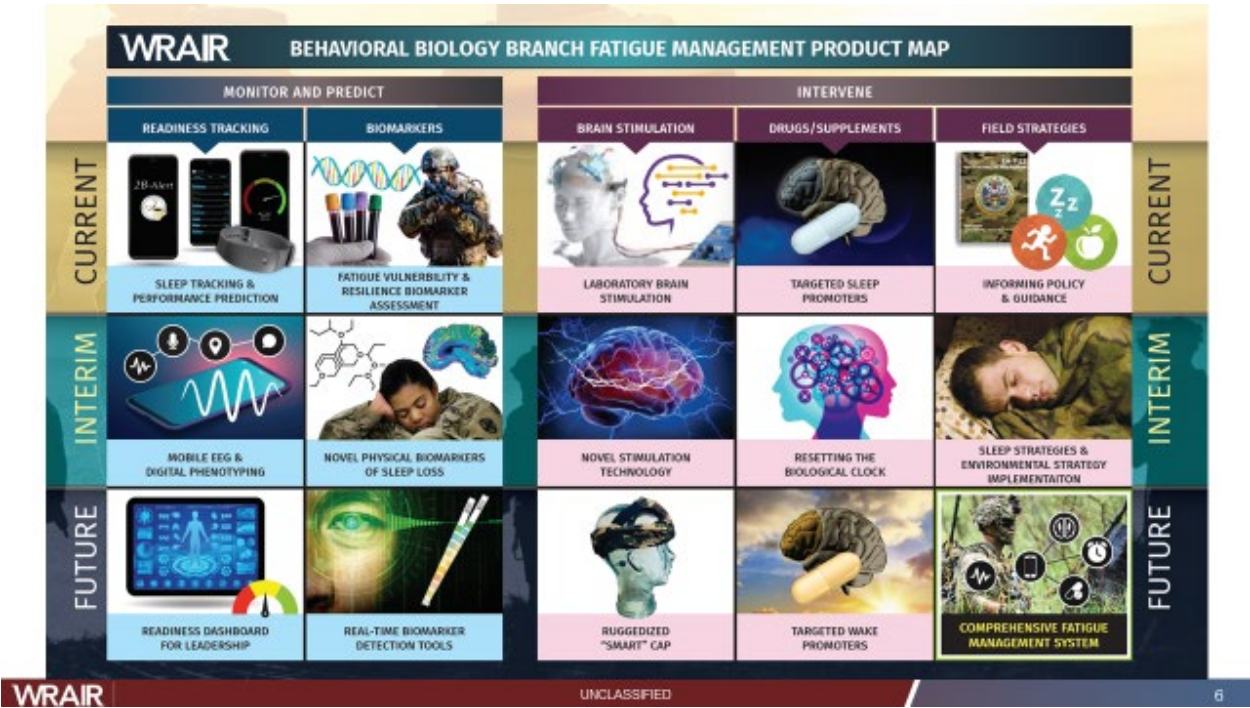


Figure 29. Behavioral Biology Branch Fatigue Management Product Map

In addition the evidence-based fatigue management strategies, the Behavioral Biology Branch is also looking forward to 2030 and 2040. Multiple, current efforts are underway to monitor and predict sleep related outcomes, along with efforts to intervene to mitigate fatigue and optimize performance. Figure 29 is a product map that shows current, interim and future efforts to monitor and predict sleep related outcomes and intervention efforts to mitigate fatigue.

Stimulation efforts to promote sleep include transcranial electrical stimulation during sleep, transcranial electrical stimulation during wake, and acoustic stimulation. Transcranial electrical stimulation during sleep seeks to determine if we can get the restorative properties from sleep in a shorter time. Methods include at-home actigraphy (7 days), in lab sleep satiation (3 nights), STIM or SHAM, sleep deprivation (46 hours) and recovery sleep (2 nights). Psychomotor vigilance testing to objectively assess alertness indicate that...Future directions of this research include optimizing stimulation parameters to maximize the acceleration of sleep restoration (e.g., current, frequency, waveform and dose); determining other situations where the method may elicit positive effects, e.g., during sustained sleep restriction (multiple days), hasten recovery from sleep

deprivation, and with healthy sleep (7+ hrs); and, utilization of a lightweight, wearable device to administer transcranial electrical stimulation in the field (Teledyne).

Administering transcranial electrical stimulation during waking seeks to determine if we can reduce sleep pressure/build-up of the need to sleep. Methods include at-home actigraphy (7 days), in lab sleep satiation (3 nights), short sleep, total sleep deprivation (46 hours) and recovery sleep (2 nights).

Efforts to study acoustic stimulation during sleep aim to determine whether we can improve recovery after sleep loss when faced with continued sleep loss. Methods include at-home actigraphy (7 days), in lab sleep satiation (3 nights), total sleep deprivation (40 hours), short sleep (5 h) with STIM or SHAM (two bouts or randomized cross-over), and recovery sleep (10 hours). Achieving restorative sleep during a five hour sleep opportunities would provide a substantial benefit to Warfighters.

An additional effort is to conduct a systematic investigation to determine tactical sleep strategies. Phase 1 will conduct novel analysis of previously-collected actigraphy data; and, Phase 2 will compare laboratory paradigms (1 consolidated nighttime sleep, 1 shorter consolidated nighttime sleep and 1 daytime nap versus 1 shorter consolidated nighttime sleep and 2 daytime naps); and, Phase 3 will assess the ideal sleep strategy identified in Phase 2 in the operational environment.

Additional work seeks to reset the biological clock using a non-invasive device to provide passive light exposure during sleep. For example, is it possible to rapidly shift the biological clock during transmeridian travel to reduce jetlag-related fatigue; and, is it possible to expedite the transition between day and night work, or to transition back to a consistent schedule more rapidly after a sustained operation.

Altogether, sleep is critical for Warfighter health, readiness and lethality. Colonel Thomas Burke (25th ID Combat Aviation Brigade Commander) said, “Sleep is not only critical for ensuring our lethality on the battlefield, but for ensuring the safety of our crews and aircraft. To that end, sleep is truly a weapon.”

Panel discussion

In terms of additional observations from the vignette, the possibility of undernutrition was acknowledged. While it is not clear, energy deficit is certainly a possibility that must be considered, the magnitude of which varies greatly depending on the mission requirements. This is an important consideration, because this will increase reliance on (and deplete) muscle glycogen stores for fuel thus compromising performance, as discussed during today’s workshop. There were no additional considerations to make the vignette more realistic or useful, beyond what has been previously discussed (i.e., Appendix C)

The discussion also addressed sleep and the culture around sleep. It’s evident that adequate sleep was not available to the protagonist in the vignette. The evidenced-based resources may be of benefit, e.g., tactical napping strategies. Additionally, the capabilities discussed today, e.g., stimulation efforts, may support getting better, higher quality sleep when sleep restriction is unavoidable. Improved sleep quality can substantially help with mood and performance. While current efforts are exploring the use of the stimulation paradigm outside of the helmet, future efforts will explore the use of stimulation devices worn inside the helmet.

Additional capabilities discussed today certainly have applicability to the vignette. For example, the ability to leverage the gut microbiome to enhance both physical and cognitive performance. When energy intake is inadequate to meet energy needs, we can optimize nutrition to provide a longer lasting substrate to the microbiome that delivers additional energy during times of need. Additionally, the capability of the

microbiome to sense biomarkers of inflammation or stress, and then respond by upregulating production of a molecule that can cope with that inflammation or stress is currently being studied (far-term deliverables). For example, engineered microbes to secrete molecules to reduce stress. Of note, similar to other interventions impacting performance, there are both risks and benefits to manipulating the microbiome. While commercially available probiotics (i.e., live bacteria) have long standing safety records with only minimal, possible side effects (e.g., mild gastrointestinal symptoms). Some prebiotics, which are given as a fuel source for the microbiome, have documented side effects as well (gastrointestinal symptoms); but, USARIEM is focusing on non-traditional prebiotics that do not exhibit these side effects. With that said, novel, next-generation probiotics haven't traditionally been used as probiotics, even if they are isolated from humans; therefore, safety profiles are required during pre-clinical and clinical studies.

Additional capabilities discussed today that apply to the vignette include pharmacological interventions. For example, the pharmacological interventions that were discussed today, if effective, may be able to alter substrate oxidation and provide fuel to the muscles to optimize and enhance performance. Minimize the use of glycogen stores, e.g., mobilizing fatty acids for energy, to prolong the use of glycogen for fuel to optimize both physical and cognitive performance.

Summary and Path Forward

This workshop series provided an opportunity to gather the broad S&T community and integrate MHP concept development work (e.g., the use of historical vignettes to identify human conditions) in order to determine the S&T necessary to achieve the required capabilities to optimize health and enhance human performance in 2040. Subject Matter Experts presented ongoing and future research on a variety of topics and discussed how related capabilities may apply to an operationally-focused vignette.

A follow-on workshop series is under consideration, wherein integrated information obtained during both the concept development process (i.e., future human-level operational environment and human performance required capabilities for Soldiers to dominate in that environment) and the initial LOE1-focused workshop series will be used to further define the S&T necessary to achieve the required capabilities for the FOE 2040. During this workshop, organizers will present multiple future-focused vignettes, addressing health and human performance, to the S&T community in order to comprehensively identify problems related to health and human performance and proposed solutions.

One key area of focus for future workshops will address biosensing. This first workshop series reinforced the notion that we have many approaches to measuring performance using biosensors, to include reliable state classification from multi-modal sensor suits, emergent predictive models of performance and methods for optimizing performance. However, many of these technologies are undergoing development independently of one another and with discrete focus areas that are not integrated. Importantly, current efforts are addressing synchronization of wearable sensors at the DoD level. A future workshop will discuss targets within the vignette for these types of closed loop systems that are likely to be embedded with dismounted operations and future vertical lift in the future.

For example, the S&T community will address the following questions:

- 1) If we could sense and classify in the vignette, what would we sense and classify?
- 2) If we could predict outcomes, what would we want to predict specifically? [what does "red" mean; what do different echelon leaders need]

- 3) If we could take one of the optimization strategies that we've discussed in the workshops (or another that we haven't touched on yet), where would we embed the technology in the vignette and what would we expect to happen.
- 4) How could all of these systems talk to each other and inform each other adaptively to overcome the challenges in the vignette.
- 5) Specify how we choose the optimization, enhancement and recovery strategies (do we implement them before, during or in the recovery period).

Altogether, this workshop series built upon the existing synchronization efforts of MHP LOE1 and expanded to include the broad S&T community in the context of optimizing health and enhancing human performance, to include cross-MHP LOE equities. The next workshop series will continue to synchronize across the S&T Army modernization enterprise to meet the human performance capabilities of Soldiers, Leaders and Senior Leaders in 2040, specifically as outlined in the Army Operating Concept of 2040 and related Army strategies.

References (alphabetical)

- Adler AB, Bliese PD, LoPresti ML, McDonald JL, Merrill JC. (2021). Sleep leadership in the army: a group randomized trial. *Sleep Health*. 7(1):24-30.
- Adler AB, Gutierrez IA. (2022a). Acute Stress Reaction in Combat: Emerging Evidence and Peer-Based Interventions. *Current Psychiatry Reports*. 30:1-8.
- Adler AB & Gutierrez IA. (2022b). Preparing Soldiers to Manage Acute Stress in Combat: Acceptability, Knowledge and Attitudes, *Psychiatry*, 85:1, 30-37.
- Adler AB, Saboe KN, Anderson J, Sipos ML, Thomas JL. (2014). Behavioral health leadership: new directions in occupational mental health. *Curr Psychiatry Rep*. 16(10), 484-490.
- Adler AB, Svetlitzky V, Gutierrez IA. (2020). Post-traumatic stress disorder risk and witnessing team members in acute psychological stress during combat. *BJPsych Open*. 6(4), e52.
- Agans RT, Giles GE, Goodson MS, Karl JP, Leyh S, Mumy KL, Racicot K, Soares JW. (2020). Evaluation of probiotics for warfighter health and performance. *Front Nutr*. 7, 70-75.
- Bavelier, D. & Green, C.S. (2019). Enhancing Attentional Control: Lessons from Action Video Games. *Neuron*. 104, P147-163.
- Bediou, B., Adams, D.M., Mayer, R.E., Green, C.S. & Bavelier, D. (2018). Meta-analysis of action video game impact on perceptual, attentional, and cognitive skills. *Psychological Bulletin*. 144(1), 77-110.
- Brunye TT, Yau K, Okano K, Elliott G, Olenich S, Giles GE, Navarro E, Elkin-Frankston S, Young AL and Miller EL. (2021). Toward Predicting Human Performance Outcomes from Wearable Technologies: A Computational Modeling Approach. *Front Phys*, <https://doi.org/10.3389/fphys.2021.738973>
- Burgoyne, AP, Hambrick DZ & Altmann EM. (2021). Incremental validity of placekeeping as a predictor of multitasking. *Psychological Research*, 85, 1515-1528.
- Claypoole VL, Killingsworth CD, Hodges CA, Nye HK, Morales LA, Ruiz E & Stanney KM. (2021). Augmented reality: Panacea or pandora's box? *Human Factors Issues and the Impact of Technology on Society*. IGI Global. <https://no-click.mil/?https://www.igi-global.com/chapter/augmented-reality/281749>
- Claypoole VL, Stanney KM, Padron CK & Perez R. (2020). Enhancing Naval enterprise readiness through augmented reality knowledge extraction. *Proceedings of the Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) Annual Meeting*. Orlando, FL. Best paper award: <https://no-click.mil/?https://designinteractive.net/design-interactive-wins-ecit-best-paper-award/>
- Claypoole VL, Padron CK, Sanchez SA, Hodges CA, Stanney KM & Perez RS. (2020). Leveraging emerging technologies for shipboard training and sailor support: recent advancements and current operational challenges. *American Society of Naval Engineers (ASNE) 2020 Fleet Maintenance & Modernization Symposium (FMMS)*. Virtual Symposium Sept 15- 16.
- Dale G, Bavelier D & Green CS. (2020). Cognitive abilities of action-videogame and role-playing videogame players: Data from a Massive Open Online Course. *Psychology of Popular Media Culture*. 9(3), 347-358.
- Dale G, Joessel A, Bavelier D & Green CS. (2020). A New Look at the Cognitive Neuroscience of Video Game Play. *Annals of the New York Academy of Sciences*. Special Issue: The Year in Cognitive Neuroscience. 1464, 192-203.

- Dale G & Green CS. (2017). The changing face of video games and video gamers: Future directions in the scientific study of video game play and cognitive performance. *Journal of Cognitive Enhancement*, 1(3), 280-294.
- Dale G & Green CS. (2017). Associations between avid action & real-time strategy game play and cognitive performance: A pilot study. *Journal of Cognitive Enhancement*, 1(3), 295-317.
- Farina EK, Thompson LA, Knapik JJ, Pasiakos SM, McClung JP, Lieberman HR. (2019). Physical performance, demographic, psychological, and physiological predictors of success in the US Army Special Forces Assessment and Selection course. *Physiol Behav.* 210, 112647.
- Farina EK, Thompson LA, Knapik JJ, Pasiakos SM, McClung JP, Lieberman HR. (2020). Diet Quality is Associated with Physical Performance and Special Forces Selection. *Med Sci Sports Exerc.* 52(1), 178-186.
- Farina EK, Thompson LA, Knapik JJ, Pasiakos SM, McClung JP, Lieberman HR. (2021). Anthropometrics and Body composition Predict Physical Performance and Selection to Attend Special Forces Training in United States Army Soldiers. *Mil Med.* doi: 10.1093/milmed/usab315.
- Friedman A, Kohler B, Gunalp P, Boone AP & Hegarty M. (2019). A computerized spatial orientation test. *Behavior Research Methods*, 52(2), 799-812.
- Gardony, A. L., Hendel, D. D., & Brunyé, T. T. (2021). Identifying optimal graphical level of detail to support orienting with 3D geo-visualizations. *Spatial Cognition & Computation*, 1-26.
- Green, C.S., Kattner, F., Eichenbaum, A., Bediou, B., Adams, D.M., Mayer, R.E., & Bavelier, D. (2017). Playing some video games but not others is related to cognitive abilities. *Psychological Science*, 28(5), 679-682.
- Gunia B, Adler AB, Bliese PD, Sutcliffe KM. (2021). How are you sleeping? Leadership support, sleep health, and work-relevant outcomes. *Occ Health Sci.* 5(9), 563-580.
- Hegarty M & Waller D. (2005). Individual differences in spatial abilities. *The Cambridge Handbook of Visuospatial Thinking*, 121-169.
- Hughes RL. A review of the role of the gut microbiome in personalized sports nutrition. *Front Nutr.* 2020;6:191.
- Jones, WE, Moss J. (2019). Assessing the transfer of interruption resumption skill to novel tasks. *Journal of Experimental Psychology: Applied*, 25(2), 230–244.
- Knapik JJ, Farina EK, Ramirez CB, Pasiakos SM, McClung JP, Lieberman HR. (2019). Medical encounters during United States Army Special Forces Assessment and Selection Course. *Mil Med.* 184(7-8):e337-e343.
- Large AM, Bediou B, Hart Y, Bavelier D & Green CS. (2019). Cognitive and behavioral predictors of achievement in a complex multi-player video game. *Media and Communication.* 7, 198-212.
- Loke G, Alain J, Yan Wei, Khudiyev T, Noel G, Yuan R, Missakian A and Fink Y (2020). *Computing Fabrics*. Matter. 2, 786-788. <https://doi.org/10.1016/j.matt.2020.03.000>.
- Mason, R.A., Schumacher, R.A. & Just, M.A. (2021). The neuroscience of advanced scientific concepts. *Nature Partner Journal Sci. Learn.* 6, 29. <https://doi.org/10.1038/s41539-021-00107-6>
- Mason, R. A., & Just, M. A. (2020). Neural representations of procedural knowledge. *Psychological Science.* 31, 729–740.
- Nassif TH, Adrian AL, Gutierrez IA, Dixon AC, Rogers SL, Jha AP, Adler AB. (2021). Optimizing performance and mental skills with mindfulness-based attention training: two field studies with operational units. *Mil Med.* usab380, <https://doi.org/10.1093/milmed/usab380>.

- Nelson MT, Charbounneau MR, Coia HG, Castillo MJ, Holt C, Greenwood ES, Robinson PJ, Merrill EA, Lubkowitz D, Mauzy CA. (2021). Characterization of an engineered live bacterial therapeutic for the treatment of phenylketonuria in a human gut-on-a-chip. *Nat Comm.* 12, 2805.
- Rahnev, D. (2021). Response bias reflects individual differences in sensory encoding. *Psych Sci*, 32(7), 1157-1168.
- Ritter FE & McDermott AF. (2020). The effect of task fidelity on learning curves. In *Proceedings of the 18th International Conference on Cognitive Modeling (ICCM 2020)*. 229-235.
- Smith TJ, Johnson B and Heaton K on behalf of Maximizing Human Potential (MHP) LOE1 Research Team. MHP Line of Effort 1 (Optimize Health and Enhance Human Performance): Inventory and Evaluation of Efforts. (2021). USAMRDC Technical Note No. TN21-01, Accession No. AD1155424.
- Srivastava S. (2021). Unifying Principles and Metrics for Safe and Assistive AI. In *Proceedings of AAAI*.
- Stepan ME, Altmann EM & Fenn KM. (2020). Effects of total sleep deprivation on procedural placekeeping: More than just lapses of attention. *J Exp Psych: General.* 149, 800-806.
- Vargas R, & Just MA. (2020). Neural representations of abstract concepts: Identifying underlying neurosemantic dimensions. *Cerebral Cortex.* 30, 2157–2166.
- Vargas R & Just MA. (2021). The neural representation of concrete and abstract concepts. In *The Cambridge Handbook of Intelligence and Cognitive Neuroscience*, A. K. Barbey, S. Karama, & R. J. Haier (Eds.), Chapter 23. Cambridge, UK: Cambridge University Press.
- Verma P, Marpally SR, Srivastava S. (2021). Asking the Right Questions: Learning Interpretable Action Models Through Query Answering. In *Proceedings of AAAI*.
- Walter Reed Army Institute of Research Behavioral Health Advisory Team. (2021). COVID-19 leader guide to health promotion.
- Wolbers T & Hegarty M. (2010). What determines our navigational abilities? *Trends in Cog Sci.* 14(3), 138-146.
- Wong AY & Moss J. (2022). Metacomprehension and regressions during reading and rereading. *Metacognition Learning.* 17, 53-71.
- Yan W, Noel G, Loke G, Meiklejohn E, Khudiyev T, Marion J, Rui G, Lin J, Cherston J, Sahasrabudhe A, Wilbert J, Wicaksono I, Hoyt R, Missakian A, Zhu L, Ma C, Joannopoulos J, Fink Y (2022). Single fibre enables acoustic fabrics via nanometre-scale vibrations. *Nature.* 603, 616-623.

Appendix A

Speakers (in alphabetical order, by last name)

Amy Adler, PhD is a clinical research psychologist and senior scientist with the Center for Military Psychiatry and Neuroscience at the Walter Reed Army Institute of Research (WRAIR). She spent more than 20 years at WRAIR's unit in Germany and has been in her present position for 5 years. Her research focuses on resilience strategies, small-team adaptability, and behavioral health leadership.

Tori Brode, MS has a Masters degree in Kinesiology. She worked as a Research Assistant at USARIEM's Military Performance Division with the Biomechanics team for 3 years before transitioning to her current position as a Research Physiologist on the DEVCOM SC Biomechanics and Engineering Team. She's been at DEVCOM SC for a little over 2 years now and she leads the 72-h field study effort, which is part of the OSD-funded MASTRE program.

Tad Brunye, PhD is principal investigator (PI) of this project and a Senior Cognitive Scientist at the DEVCOM Soldier Center, a Scientific Manager at the Center for Applied Brain and Cognitive Sciences (CABCS), and Visiting Associate Professor at Tufts University. Dr. Brunye has over 15 years of experience as a defense scientist, is internationally recognized for his contributions to the cognitive and behavioral sciences (including a Presidential Early Career Award), and holds over 150 publications in this domain. He received his doctorate in Experimental Cognitive Psychology from Tufts University in 2007, a Master of Science from Tufts University in 2004, and BS from Binghamton University in 2002. His current research areas emphasize the monitoring of cognitive states and readiness, predicting cognitive and physical performance outcomes, and leveraging emergent technologies (including brain/cognitive training, neurostimulation, nutritional supplementation) to optimize and enhance cognitive performance.

Tina Burke, PhD is the Acting Director for the Behavioral Biology Branch at Walter Reed Army Institute of Research. The Behavioral Biology Branch seeks to explore and develop strategies and technologies for monitoring, preventing, and/or reversing the decremending effects of sleep loss, fatigue, and traumatic stress to enhance Warfighter readiness and operational performance. Today she will be presenting on current efforts for fatigue management underway at WRAIR.

John Castellani, PhD is a Research Physiologist and the Deputy Division Chief in the Thermal and Mountain Medicine Division at the U.S. Army Research Institute of Environmental Medicine in Natick, MA. His research interests are in environmental and exercise physiology, primarily in the areas of human thermoregulation and performance sustainment in cold weather environments. He has served on numerous NATO Human Factors and Medicine Panels that focused on cold-weather operations and medicine, and was the co-chair and lead writer for the American College of Sports Medicine (ACSM) Position Stand, "Prevention of Cold Injuries during Exercise" (2005) and "ACSM Expert Consensus Statement: Injury Prevention and Exercise Performance during Cold-Weather Exercise" in 2021.

Matt Coppock, PhD is a team leader and chemist within the Biological and Biotechnology Sciences Division at the DEVCOM Army Research Lab. His team focuses on the development and integration of novel materials for applications ranging from biosensing to coatings.

Emily Farina, PhD, RD is a Research Nutritionist and Registered Dietitian in the Military Nutrition Division of the U.S. Army Research Institute of Environmental Medicine (USARIEM). Dr. Farina's current work aims to

identify nutritional, psychological, and physiological predictors of performance and success in Special Forces and general military populations. Her prior work has focused on examining the effects of combat deployment on diet quality, nutritional status, and physiological status among U.S. Army Special Operations Forces Soldiers. Dr. Farina's other research interests include characterizing dietary supplement use and resiliency among military personnel.

Stephen Foulis, PhD has been research physiologist for the U.S. Army since 2013. He has a Ph.D. in kinesiology from the University of Massachusetts Amherst. His research focuses on Soldier physical performance optimization and injury prevention, particularly in the Basic Combat Training environment.

Aaron Gardony, PhD is a research psychologists with the Cognitive Science and Applications Team at DEVCOM Soldier Center. Dr. Aaron Gardony has a joint Ph.D. in Cognitive Science and Psychology from Tufts University and currently has research interests and expertise in augmented/virtual reality, human computer interaction, spatial cognition, and learning science. Aaron leads the Soldier Optimized Augmented Reality for Enhanced Tactical Decision Making effort under the MASTR-E Program.

Grace Giles, PhD is a research psychologists with the Cognitive Science and Applications Team at DEVCOM Soldier Center. Dr. Giles has a PhD in Psychology from Tufts University and currently has research interests and expertise in exercise, nutrition, emotion, and cognition. Grace leads the Measurement and Prediction of Close Combat Task Performance effort under the MASTR-E Program.

Benjamin Goldberg, PhD is a Senior Scientist at the U.S. Army Combat Capabilities Development Command (DEVCOM) Soldier Center, Simulation and Training Technology Center (STTC) in Orlando, FL. He has been conducting research in the Modeling & Simulation community for the past fourteen-years with a focus on adaptive learning in simulation-based environments and how to leverage Artificial Intelligence tools and methods to create personalized learning experiences. Currently, he is the lead scientist on a research program developing adaptive training solutions in support of the Synthetic Training Environment (STE) and is project lead on the STE Experiential Learning for Readiness (STEEL-R) effort. Dr. Goldberg is co-creator of the award winning Generalized Intelligent Framework for Tutoring (GIFT) and holds a PHD from the University of Central Florida in the program of Modeling & Simulation.

Jay Goodwin, PhD (ST – Personnel Sciences) is the Senior Research Scientist of the U. S. Army Research Institute for Behavioral and Social Sciences (ARI). He advises ARI's Director on scientific matters, mentors ARI's scientific staff, and provides guidance and oversight of the Team Effectiveness portfolio of research across ARI's research program. He is one of the Army's senior scientific experts on topics in personnel science for Army senior leaders. He advises the Army's Talent Management Task Force (ATMTF) and is coordinating ARI's efforts in support of the ATMTF. He also leads the Talent Management line of effort (LOE3) within Army Future Command's Maximizing Human Potential. Dr. Goodwin's research expertise is in team and organizational effectiveness, leadership, and cultural factors in Joint, Interagency, and Multinational contexts. Dr. Goodwin received his M.S. and Ph.D. in Industrial/Organizational Psychology from the Pennsylvania State University. He is a Fellow of the Society for Industrial and Organizational Psychology and the American Psychological Association (APA).

Gregory Goodwin, PhD is a Team Leader and Senior Research Scientist at the Combat Capabilities Development Command – Soldier Center in Orlando, FL. Dr. Goodwin received his M.A. in Psychology from Wake Forest University in 1989 and his Ph.D. from Binghamton University in 1994 in Neuroscience. Dr. Goodwin's work focuses on the implementation of Army digital training strategies, the use of automated

performance assessment tools to improve marksmanship training, the use of intelligent tutoring systems to improve training outcomes, and the use of automated assessments of performance during mission training.

Reed Hoyt, PhD earned a PhD in Physiology from Univ. of New Mexico and completed a post-doctoral fellowship and Research Assistant Professorship at the Univ. of Pennsylvania. He joined USARIEM in 1986 as a Research Physiologist and served as Division Chief of USARIEM's Biophysics and Biomedical Modeling Division from 2006 – 2019. His work focuses on the research & development of real-time situational awareness products that protect Warfighter health, optimize performance, and reduce risk of injury due to exposure to extreme environmental conditions.

Julie M. Hughes, Ph.D. is a Research Physiologist in the Military Performance Division at the United States Army Research Institute of Environmental Medicine (USARIEM) in Natick, Massachusetts. Dr. Hughes completed her Bachelor's degree at the University of St. Thomas in St. Paul, Minnesota, and her doctoral degree at the University of Minnesota. Her research focuses on identifying the etiological underpinnings of stress fracture and practical solutions for musculoskeletal injury prevention.

Joan Hall Johnston, PhD has recently retired (Feb 2022) and was a Senior Research Scientist and Research Psychologist with the Training and Simulation Division of the Natick Soldier Center in Orlando, FL. Dr. Johnston began her military research career with the Naval Air (NAVAIR) Warfare Center Training Systems Division in 1990 and became In Unit Chief of the Army Research Institute's Orlando Unit 2012. Dr. Johnston's research has focused on team processes in military operations. She led the Navy's Tactical Decision Making Under Stress (TADMUS) program and was a primary investigator on the Army's Squad Overmatch project which focused on training team processes in the context of complex squad missions.

J. Philip Karl, PhD, RD is a Nutrition Scientist in the Military Nutrition Division at the U.S. Army Research Institute of Environmental Medicine (USARIEM). Dr. Karl's research aims to characterize how diet, stress and the gut microbiome interact to impact human physiology, and to identify strategies for leveraging the gut microbiome to improve health and performance. Dr. Karl is active in the U.S. Department of Defense microbiome and nutrition communities, and currently serves on the steering committee of the DoD Tri-Service Microbiome Consortium and as Chair of the Defense Health Program Joint Program Committee-5 Nutrition and Dietary Supplements Working Group.

Gregory Lieberman, PhD is a cognitive neuroscientist at DEVCOM Army Research Laboratory (ARL), where he leads Maximizing Human Potential Line of Effort 2: Optimizing Human-System Performance. Dr. Lieberman has contributed to and led academic research efforts centered on developing treatments for neurodegenerative disease, understanding the learning theory and neural mechanisms underlying fear and anxiety, exploring the neuroplastic mechanisms of chronic pain and mild traumatic brain injury pathology and recovery, and innovation of novel interventions to enhance cognition. He has also led or contributed to high-priority Army research on brain-computer interfaces; human variability, performance, cognition, and expertise development; and teaming with intelligent technologies. Dr. Lieberman's passion, technical expertise, and leadership philosophy converge on empowering people, streamlining processes, developing novel tools, and integrating all three to maximize human potential.

Lee Margolis, PhD, RD began his nutrition research career as a uniformed dietitian stationed at the US Army Research Institute of Environmental Medicine (USARIEM) in Natick, MA. There he organized, supervised, and led field studies assessing the energy needs of Special Operations Forces during various training scenarios. After leaving the military, Dr. Margolis received his doctoral degree in Biochemical and Molecular Nutrition

from Tufts University. Dr. Margolis is currently a Nutrition Physiologist in the Military Nutrition Division at the USARIEM. His research program aims at determining viable nutrition and pharmacological interventions to enhance Warfighters performance during sustained dietary inadequacy, heavy physical activity, and exposure to environmental extremes.

Mr. John Player. John has spent most of his career in industry doing R&D on a variety of novel biomedical devices such as a shape memory alloy based neurosurgical robot and braided composite prosthetic limbs. He is currently a team leader for biological sciences with the Solder Effectiveness Directorate of DEVCOM Soldier Center and his team is currently engaged in basic and early applied research efforts associated with the gut and skin microbiomes as well as translational research as part of the MASTRE program.

Roy M. Salgado, PhD is a Research Physiologist in the Thermal and Mountain Medicine Division at the U.S. Army Research Institute of Environmental Medicine (USARIEM) in Natick, MA. His research interest is in environmental and exercise physiology with a focus in high altitude environments and environmental cross-adaptation. His current work is aimed at identifying countermeasures (training practices, pharmaceutical/nutritional) to sustain performance and reduce acute mountain sickness during exposure to high altitude. He is an author or co-author on 20 peer-reviewed scientific papers.

MAJ Carl Smith, PhD is the Director of the Research Transition Office at the Walter Reed Army Institute of Research. He has been at WRAIR since 2020 and directs RTO's efforts in translating research into fielded psychological health products. The RTO is responsible for transitioning training materials, educational resources, and policy within the psychology-related fields including resilience, suicide prevention, ethical leadership, team cohesion, mindfulness, and moral injury. MAJ Smith's team supports these efforts through curriculum development, training, field evaluations, and advanced quantitative and qualitative analyses.

Tracey Smith, PhD, RD is the Deputy Chief of the Military Nutrition Division (MND) at the U.S. Army Research Institute of Environmental Medicine (USARIEM, Natick, MA). Dr. Smith earned her Doctoral degree in the School of Health Related Professions at Rutgers, The State University of New Jersey (2011). She is a Registered Dietitian and is a certified Exercise PhysiologistSM (American College of Sports Medicine). Dr. Smith began as a research dietitian in USARIEM's Military Nutrition Division (2002) and has been a principal investigator since 2010. Dr. Smith's research primarily focuses on nutrition interventions to support immune recovery. In addition to her duties as Deputy Chief of MND, Dr. Smith is the Chair of the USARIEM Credentials Committee and represents USARIEM and MRDC Headquarters for strategic planning efforts to maximize human physical, cognitive and emotional potential (to include leading Line of Effort 1 to optimize health and enhance human performance for AFC efforts to maximize human potential for 2040+). Dr. Smith is a member of the Academy of Nutrition and Dietetics and the American Society of Nutrition and a reviewer for various peer-reviewed journals.

Paul St. Onge, PhD is the Applied Solutions Team Lead in the Warfighter Performance Group at the United States Army Aeromedical Research Laboratory, Ft. Rucker, Alabama. His current research projects focus on developing physiological based operator state monitoring techniques, the combined impact of hypoxia and time-on-task on performance, and using virtual reality headsets to induce vection - the sense of movement generated by visual allusions. As part of a multidisciplinary team he is exploring the development of a cognitive workload objective metric that is akin to the well-established cardiac stress test and VO2max. Additionally, he is exploring advanced methodologies to objectively quantify cognitive workload in professionals engaged in their domain of expertise as a tool for developing and evaluating enhanced information presentation systems

designed to aid pilots. He is engaged in multiple Cooperative Research and Development Agreements and is a mentor to participants in the Oakridge Institute for Science and Education internship program.

Kathryn Taylor, PhD is a Research Epidemiologist in the Military Performance Division and Director of the Soldier Performance Health and Readiness (SPHERE) Database at the US Army Research Institute of Environmental Medicine. Dr. Taylor received a Master of Science degree in Epidemiology and a Doctorate of Science in Environmental Health from Harvard University where she studied the impact of traumatic brain injuries on neurological health throughout the life-course. Her current research primarily focuses on quantifying the impact of military relevant occupational risk factors on injuries and neuropsychological health endpoints in military personnel and evaluating the long-term implications of these health outcomes on military readiness and resiliency.

Phillip Quartana, PhD is a research psychologist in the Center for Military Psychiatry and Neurosciences at the Walter Reed Army Institute of Research. During his 10 years in this position, he has studied a multitude of factors related to behavioral and psychological health in Soldiers, including sleep deprivation, cognitive bias, anger, and PTSD. Most recently, he has been leading the U.S. Army's Behavioral Health Advisory Team (BHAT) to study the behavioral and public health impact of the COVID-19 pandemic on Soldiers and their families. Finally, he is currently serving as a Capability Area Manager for a number of Far Forward Behavioral Health functional objectives under the MOMRP Psychological Health and Resilience Research Program.

Appendix B

Vignette #1a

Applied during LOE1-focused Ignite Workshops November 2021-February 2022

Tactical Operations Center I

Introduction

This vignette is set in the Tactical Operations Center (TOC) of a Combined Arms Battalion (CAB). The protagonist is the Battalion Operations Sergeant Major, who is responsible for the setup and operations of the TOC. This battalion has been in several days of active operations and the TOC has had to jump or change locations throughout this period. At the start of the vignette, the TOC with its various vehicles are on the road jumping to its next location.

1 “Damn it!” The vibration off the road and the rumble of the engine was making it hard to keep his eyes
2 open, despite the morning chill. He shifted his weight in the command hatch of the M1209, pulled up
3 the scarf over his face and wiped his goggles, which was more like smearing the mud enough that he
4 could see through the eyepieces. He rubbed hard at the back of his neck to try to get that pain to go
5 away. Twisting, he looked behind him to see the two other 09s still following, plus the first of several
6 CTVs¹.

7 He peered down again at his map. They should be there just up ahead, around the bend. A few
8 moments later, he could just see a CTV off the road at the opening of a forest trail. A Soldier, that would
9 be Lieutenant Ang the SIGO², was standing next to it, waving at them. He waved back and watched the
10 LT jump back in the truck.

11 11 “Driver, you see the SIGO?” he asked Specialist James, his driver, over the intercom.

12 12 “Yes Sergeant Major,” came the response.

13 “Ok, follow him.” He turned in the hatch, signaled the next vehicle, and then bent down to look into the
14 back of the vehicle. The Captain and Sergeant Willis were at the two workstations, earphones on and
15 fiddling with the C2³ equipment. Also in the compartment were two more Soldiers who had made
16 themselves nooks between all the extra junk the vehicle carried. They seemed to be dozing. “Get ready,
17 we are leaving the main road,” he shouted at the two with headphones. The sleepers could take care of
18 themselves.

19 He got up just in time for the 09 to take a hard right, cutting the corner of the exit and giving the vehicle
20 a good bounce. He was not ready and hit the side of the hatch hard. “Fucking James,” he thought. “She
21 did that on purpose.” The Captain came over the intercom, “Hey, what the hell?” Of course, it would
22 have been more safe for James to have slowed down, but he had pounded into James’ head, speed is
23 safety, especially when they were exposed on a road. He glanced back and checked that the next vehicle
24 had made the turn. Yes. Turning back to the front, a few hundred meters forward of him he could see
25 the SIGO’s truck, moving fast and slipping and sliding in the mud of the track, throwing “rooster tails” of
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97 go of the driver, pointing towards the Sergeant Major. The Air Defense NCO looked briefly at the
98 Sergeant Major, and then turned towards her Lieutenant.
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123 How long has it been since you had any shut-eye?"
124 "I'm good Sergeant Major, but thanks." She turned and walked away. He took another sip before turning
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126 was shaking her head but Alvarez kept pointing to the remote. Everything else seemed to be in place.
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128 reached in to grab his go-bag sitting next to the ramp. He pulled out a meal bar, peeled it back and
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 139 flipped it around to show him. Each listed the names of their Soldiers and a status indicator. He looked
 140 down at his own tracker. With few exceptions, everyone was Red. Even the Major was red. He looked at
 141 Lewis.
 142 "Where the hell is your Thomas? Did he die on us?" Specialist Thomas had no status.
 143 "No Sergeant Major, his shit is just not working."
 144 "Ok, pick your worse shaped Soldiers and put them down." He looked around the outside of the
 145 clearing. "Put them down over there," he said, pointing to a spot with three or four thick trees. No one
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 148 Captain. He was going to tell James to rest plus a Soldier working for the Battle Captain and wanted to
 149 make sure the Captain knew who he had picked.
 150 The Major had a mike in his hand. "Rampage zero-three tango, this is zero five, over."
 151 "Zero five, this is zero-three tango, over," the radio responded.
 152 "Zero-three tango, this is zero five. Rampage three-three is set and prepared to take the fight, over."
 153 "Roger, wait," the voice at the TAC responded. "Confirm you are current with the fight, over."
 154 The Major looked at the Captain. She nodded ascent, though she quickly looked back down at the
 155 comms remote, probably checking on whether Alpha Team was showing any activity.
 156 "This is zero-five, we are current."
 157 "Roger, zero five, then you have the fight."
 158 "Roger, out" finished the Major. The Captain turned to one of her Soldiers in the back of the 09. "Call
 159 Brigade and tell them we have the fight," she ordered.
 160 Good, done, and not too slowly. But then, it was like all the air left him. He suddenly felt his eyes flutter
 161 and pain in both arms.
 162 "Excuse me, Sergeant Major." He turned to see the ADA Lieutenant addressing him.
 163 Yes, El Tee?" he answered, an edge entering into his voice. He knew what this was going to be about and
 164 the LT was making a big mistake.
 165 "Did you take my driver?" asked the Lieutenant.
 166 "She's pulling security," he answered, turning to directly face the officer.
 167 "That's bull, Sergeant Major! She works for me, not you."
 168 "He's part of this TOC, Lieutenant, and she is going to help with security, especially when everyone else
 169 is working and she's sleeping."
 170 "No, Sergeant Major, we were not sent here to do your work and we do not answer to you!" the young
 171 officer spat out.
 172 "You won't do what? You little pipsqueak officer!" His voice started to raise. "If you think every other
 173 Soldier here is going to put their lives on the line to keep your ass warm and safe, I've got something
 174 else to tell you!" He took a step toward the Lieutenant, tossing away his cup. "You can just get the hell
 175 out of my TOC!"
 176 "What?" the Lieutenant looked shocked. "You cannot tell me that. I'm an officer."
 177 "I don't give a shit what you are!" he was now yelling, taking another step toward the officer and
 178 pointing out towards the woods. "YOU CAN JUST GET THE HELL OUT OF MY TOC!"

179 The Lieutenant was backing up and now his sergeant had grabbed him and was pulling him away. The
180 Sergeant Major spun around. Fuck this! He stopped. Everyone was looking at him.
181 The Major stepped up. "Sergeant Major, when was the last time you got some sleep?"
182 "I am fine, sir."
183 "No, you are not and we cannot afford to lose you. You need to go follow your Soldiers over to those
184 trees. I want to see you on your back, boots off. That's an order."
185 He stared at the Major. The pain behind his eyes was pounding. Ok. Ok. This seems to be a good time to
186 shut them. "Ok, Major. Yes sir."
187 He turned to grab a jacket to wrap up in. Then Lewis literally jumped out of his 09.
188 "Sir, we just got a message from Division. We are being targeted!" Lewis blurted.
189 "What?"
190 "Division got an intercept, sir. We are being targeted!"
191 Fuck rest! "Everyone, grab our stuff! Go! Go!" the Sergeant Major yelled. "All NCOs, get immediate
192 accountability of every troop you have!" he continued, as the group of Soldiers exploded back into
193 action.

¹ CTV – Combat Tactical Vehicle

² SIG O – Signal Officer

³ C2 – Command and Control

Appendix C

Vignette #1b

Applied during LOE1-focused Ignite Workshops March 2022 Tactical Operations Center I

Introduction

This vignette is set in the Tactical Operations Center (TOC) of a Combined Arms Battalion (CAB). The protagonist is the Battalion Operations Sergeant Major, who is responsible for the setup and operations of the TOC. This battalion has been in several days of active operations and the TOC has had to jump or change locations throughout this period. At the start of the vignette, the TOC with its various vehicles are on the road jumping to its next location.

7 “Damn it!” The vibration off the road and the rumble of the engine was making it hard to keep his eyes
8 open, despite the morning chill. The cold had stiffened his face and with each breath, he could see the
9 fog highlighting how cold it really was. He shifted his weight in the command hatch of the M1209, pulled
10 up the scarf over his face and wiped his goggles, which was more like smearing the mud enough that he
11 could see through the eyepieces. He rubbed hard at the back of his neck to try to get that pain to go
12 away. Twisting, he looked behind him to see the two other 09s still following, plus the first of several
13 CTVs¹.

14 He peered down again at his map. They should be there just up ahead, around the bend. A few
15 moments later, he could just see a CTV off the road at the opening of a forest trail. A Soldier, that would
16 be Lieutenant Ang the SIGO², was standing next to it, waving at them. He waved back and watched the
17 LT jump back in the truck. “Driver, you see the SIGO?” he asked Specialist James, his driver, over the
18 intercom. 18 “Yes Sergeant Major,” came the response.

13 “Ok, follow him.” He turned in the hatch, signaled the next vehicle, and then bent down to look into the
14 back of the vehicle. The Captain and Sergeant Willis were at the two workstations, earphones on and
15 fiddling with the C2³ equipment. Also in the compartment were two more Soldiers who had made
16 themselves nooks between all the extra junk the vehicle carried. They seemed to be dozing. “Get ready,
17 we are leaving the main road,” he shouted at the two with headphones. The sleepers could take care of
18 themselves.

19 He got up just in time for the 09 to take a hard right, cutting the corner of the exit and giving the vehicle
20 a good bounce. He was not ready and hit the side of the hatch hard. “Fucking James,” he thought. “She
21 did that on purpose.” The Captain came over the intercom, “Hey, what the hell?” Of course, it would
22 have been more safe for James to have slowed down, but he had pounded into James’ head, speed is
23 safety, especially when they were exposed on a road. He glanced back and checked that the next vehicle
24 had made the turn. Yes. Turning back to the front, a few hundred meters forward of him he could see
25 the SIGO’s truck, moving fast and slipping and sliding in the mud of the track, throwing “rooster tails” of
26 it behind it. James stayed out of that, at least. This trail had been used before and there were ruts from
28 heavy vehicles. The 09 slipped into and out of them, tossing it back and forth, while the antennas
29 whipped the tree branches overhead, knocking the cold remains of the last rain onto them. “Fuck!” He
30 held tight trying to wedge himself against the side of the hatch.

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31 and then spun his hand over his head. He had picked this spot for their next TOC location and was telling
32 him to laager. Pretty normal. Not a bad spot, far enough in the trees that they would not be seen from
33 the road and on a rise. Even the opening was relatively undamaged, with a few small trees and tall grass.
34 They would follow SOP to keep from tearing up the center. He turned and signaled Sergeant First Class
35 Lewis TC’ing the S-2’s 09, the next in line, to go right. He then told James to take a wide turn to the left,

36 following the outside of the clearing. At the right time, he ordered her to turn hard left, and then to back
37 up towards the center. Lewis was mirroring him. "Straight back, steady, steady, stop!" The two 09s were
38 now ass backwards to each other, about a vehicle length apart. "James, drop the ramp." He pulled off
39 his CVC and grabbed his helmet, climbing down from his command position and into the back of the 09.
40 "Damn!" He had to pause. "What the fuck?" His vision had tunneled and he felt drained. "Fuck it!" He
41 shook his head and then rubbed his eyes. His arms felt heavy as cement. His knees ached. The whiskers
42 on his cheeks and chin itched and he could feel the crud on his face. Then vision was back. "Fuck it!"
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45 maneuvered around the Captain and the Sergeant in their seats and walked down the 09 ramp. The
46 third 09, this one belonging the Fire Support Officer, was just backing up to the central ground. The FSO
47 Captain was forward in the TAC tailing the Old Man and Staff Sergeant Alvarez was in charge of the
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50 up just between the 09s, the three vehicles creating a small, common workspace, which would receive
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171 "No, Sergeant Major, we were not sent here to do your work and we do not answer to you!" the young
172 officer spat out.

173 "You won't do what? You little pipsqueak officer!" His voice started to raise. "If you think every other
174 Soldier here is going to put their lives on the line to keep your ass warm and safe, I've got something
175 else to tell you!" He took a step toward the Lieutenant, tossing away his cup. "You can just get the hell
176 out of my TOC!"

177 "What?" the Lieutenant looked shocked. "You cannot tell me that. I'm an officer."

178 "I don't give a shit what you are!" he was now yelling, taking another step toward the officer and
179 pointing out towards the woods. "YOU CAN JUST GET THE HELL OUT OF MY TOC!"

180 The Lieutenant was backing up and now his sergeant had grabbed him and was pulling him away. The
181 Sergeant Major spun around. Fuck this! He stopped. Everyone was looking at him.

184 The Major stepped up. "Sergeant Major, when was the last time you got some sleep?"

185 "I am fine, sir."

184 "No, you are not and we cannot afford to lose you. You need to go follow your Soldiers over to those
185 trees. I want to see you on your back, boots off. That's an order."

186 e stared at the Major. The pain behind his eyes was pounding. Ok. Ok. This seems to be a good time to
187 shut them. "Ok, Major. Yes sir."

190 He turned to grab a jacket to wrap up in. Then Lewis literally jumped out of his 09.

191 "Sir, we just got a message from Division. We are being targeted!" Lewis blurted.

192 "What?"

193 "Division got an intercept, sir. We are being targeted!"

194 Fuck rest! "Everyone, grab our stuff! Go! Go!" the Sergeant Major yelled. "All NCOs, get immediate
195 accountability of every troop you have!" he continued, as the group of Soldiers exploded back into
action.

Appendix D

Summary of observations from the vignette

- The group is operating in conditions of uncertainty
- Protagonist has mud on the goggles which leads to reduced visibility
- Sore neck from poor posture; other potential MSKI risk from posture
- General lack of trust and cohesion
 - Interpersonal challenges (echelon based) & escalation of interpersonal conflict towards the end
 - Lack of communication or inappropriate communication between leaders and subordinates
 - Psychosocial metrics increase risk of injury
 - Stress (e.g., anger illustrated by the protagonist) repeatedly can impact bone formation and related processes (also with inadequate sleep quality/quantity and inadequate energy). Multiple stressors over long period of time increase MSKI risk.
- Severe lack of sleep and poor quality when they could sleep; opportunity for sleep at the end that was cut short (all increases MSKI risk)
- Status tracker indicated that everyone was in “red” and someone wasn’t updating at all
 - Long term (months/year) data from status trackers can be helpful to determine injury risk [not just acute responses, but chronic conditions, as they can accumulate over time].
- Possibility of undernutrition, e.g., inadequate energy intake to match energy needs
- Potential caffeine withdrawal

Additional considerations to make the vignette more realistic:

- Further expound upon the environmental extremes and hydration issues
- Modernize the technology that is being used in the field
- Consider adding more stressful conditions, e.g., in an operational environment, units may be more “on the offensive” (received and sending fire), which leads to a highly pressurized situation.
- Present multiple future-focused vignettes, addressing health and human performance, to the S&T community in order to comprehensively identify pain points and propose solutions
 - This notion was discussed during various workshops as a means to more comprehensively identify human-level conditions, “pain points” and S&T solutions. This workshop series has discussed one historic vignette, which will be used during the MHP concept development process. Future LOE1-focused workshops present, review and discuss additional, future-focused, vignettes, to identify problems related to health and human performance and S&T solutions within the LOE1 space.
- Include both mission planning and operational elements in the vignette (e.g., perhaps a separate vignette that incorporates these elements).
- Consider including baseline state (how does the soldier come into the vignette ahead of time, e.g., dehydration, sleep status, etc...)
 - While this is possibility, this baseline information will not always be available to leaders.

- Consider additional solutions that we working on in the S&T space that would benefit the protagonist in this vignette.
 - Challenges related to Soldier adaptation to extreme environments (extreme hot/cold, enclosed spaces, high altitudes) and physical demands (e.g., load carriage)
 - Fitness, hydration and nutrition management
 - Self-awareness/mindfulness strategies
 - Injury prevention strategies
 - Recovery strategies
 - The collective modeling work to monitor and predict operationally relevant performance outcomes
 - Strategies to optimize leadership and team dynamics
 - Other methods, not previously mentioned, to optimize and enhance all aspects of performance
- Consider additional vignettes and vignettes with future-focused elements
 - A vignette targeting aviator state monitoring, to include more near-term targets, e.g., accessing data thru external sensors to give insight into aviator/operator states to feed into cockpit dashboard and feedback systems.
 - MHP concept development team has defined the future human-level environment and the MHP community is discussing capabilities required to succeed in that environment. The S&T community will review/apply additional vignettes to more comprehensively identify the S&T necessary to deliver the required capabilities to optimize health and enhance human performance in the FOE 2040+. For example, future LOE1-focused workshops may present, review and discuss additional, future-focused, vignettes, to identify problems related to health and human performance and S&T solutions within the LOE1 space.