WARFIGHTER PERFORMANCE

Office of Naval Research, Code 34

ONR Warfighter Performance at MHSRS 2023

Mission

The Warfighter Performance department's mission is to enhance warfighter effectiveness and efficiencies through bioengineered and biorobotic systems, medical and behavioral technologies, improved manpower, personnel, and training and systems design.

Vision

- Enhance individual and team decision-making, as well as combat effectiveness, by supplying the correct information to the right people with the required skills at the proper time in the right jobs
- Realize human-system efficiencies to enhance performance and reduce costs
- Create and deliver technologies inspired by biological systems
- Ensure the health and viability of our warfighters afloat and ashore

Department Contact Information

Dr. Patrick Mason, SES
Department Head
Warfighter Performance
patrick.a.mason2.civ@us.navy.mil

Dr. Michael LaFiandra
Division Director
Code 341/342
michael.e.lafiandra.civ@us.navy.mil

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WARFIGHTER PERFORMANCE
Code 34 Divisions

Human & Bioengineered Systems (Code 341)

Goals
- Sustained and improved warfighter performance and enhanced decision making in all environments through training and biomedical technologies
- Create options for future (perhaps unanticipated) naval decisions, based upon fundamental understanding gained from cognitive and neurosciences
- Support integrated interdisciplinary research programs
- Cultivate transition of findings to government and industry, advanced technology development, small business and acquisition projects

Areas of Interest

ONR's Human and Bioengineered Systems Division seeks innovative proposals in basic research through applied research. Current research areas of interest include, but are not limited to:
- Biometrics and Human Activity Recognition
- Cognitive Sciences
- Computational Neurosciences and Biorobotics
- Human Factors, Organizational Design and Decision Research
- Social, Cultural, and Behavioral Modeling
- Training, Education and Human Performance

Warfighter Protection and Applications (Code 342)

Goals
- Increase the survival of casualties through immediate, life-saving treatment and stabilization
- Prevent stress-induced injury and performance degradation in naval occupations and environments
- Optimize warfighter selection, training and team dynamics
- Mitigate health and performance risks in undersea operations

Areas of Interest

The Warfighter Protection and Applications Division seeks technology solutions from a wide range of scientific and engineering disciplines including, but not limited to, biology, physiology, pharmacology, computer and behavioral sciences, and systems engineering. The current S&T programs are:
- Auditory Performance
- Basic Physiological Sciences
- Biotechnology for Naval Applications
- Expeditionary Robotics, Autonomic and Autonomy
- Marine Mammal Health
- Naval Force Health Protection
- Stress Response
- Undersea Medicine and Performance

Research Protections (Code 343)

The mission of the Research Protections Division is to ensure that human subject research supported by DON complies with federal regulations, DoD directives, and SECNAVINST 3900.39E CH-1. This includes all research involving human subjects conduced at DON systems and training commands, in operations forces, and at extramural institutions sponsored by the Navy.

WARFIGHTER PERFORMANCE
Code 34 at MHSRS 2023

Monday August 14, 1pm-2pm

Biomedical Community of Interest: Understanding and Learning From the Ukraine Conflict

Session Presenter: Dr. Patrick Mason, Warfighter Performance Department Head

Wednesday August 16, 1pm-3pm

Surviving and Thriving in a Distributed Operations Environment: Military Health Challenges and Solutions

Session Co-moderator: Dr. Michael LaFiandra, Warfighter Performance Division Director, 341/342

Naval Force Health Protection

Dr. Timothy Bentley (timothy.b.bentley6.civ@us.navy.mil), Program Officer, Code 342

The aim of the Naval Force Health Protection program is to research and develop innovative capabilities to protect the warfighter, reduce injury risk and improve combat casualty care while also optimizing performance. The program seeks basic and applied research in neuroscience, bioengineering, biophysics, bio-nano-technology, autonomy and material science to understand the underlying mechanisms of injury and repair, which can be applied broadly to ensure Naval Force Health Protection and Readiness.

Undersea Medicine and Performance

Dr. Sandra Chapman (sandra.e.chapman2.civ@us.navy.mil), Program Officer, Code 342

The aim of Undersea Medicine and Performance is to develop improved methods, models, treatments and devices for understanding, preventing or mitigating factors that negatively impact divers and submariners. Solutions should extend warfighting capability during undersea operations to maximize freedom of action and warfighter dominance.

Basic Physiological Sciences

LCDR Garrett Morgan (richard.g.morgan3.mil@us.navy.mil), Program Officer, Code 342

This portfolio aims to invest in fundamental and applied human physiology and human factors focused research efforts that are relevant to contemporary and projected U.S. Navy and U.S. Marine Corps operational capability gaps. Current portfolio focus areas include gaining an improved understanding of and developing interventions aimed at improving efficiency of shipboard damage control activities and ultimately ship recoverability; survivability of sailors engaged in shipboard damage control activities; and sailor survivability at sea.

Manpower, Personnel, Training and Education Information Sciences

CDR Jacob Norris (jacob.n.norris.mil@us.navy.mil), Program Officer, Code 341

The Manpower, Personnel, Training, and Education Information Sciences portfolio funds basic and applied research in metrics development, data ontology, data mining and machine learning to optimize performance, personnel screening, training and education opportunities for the warfighter within the Naval enterprise. An underlying premise for all efforts within the portfolio is adherence to sound measurement principles best summarized as reliability (precision) and validity (accuracy). The program examines various learning and assessment modalities including mobile devices, virtual/augmented realities, and commercially available physiological monitors. The overarching goals are to supply seasoned Naval forces who will “outthink, outfight any adversary” in today and tomorrow’s operational environment, as well as reduce unplanned losses & improve retention.

ONR Funded Research at MHSRS
TABLE OF CONTENTS

ONR Funded Research at MHSRS
TABLE OF CONTENTS

Tuesday, 15 August | 0830-0845
BREAKOUT SESSION: Development and Validation of Sensors and PPE for Blast Polytrauma

Design Development and Optimization of Novel Flexible Capacitive Pressure Sensors for Blast Overpressure Measurement
Oral Presentation by Dr. Neda KaramiMohammadi (Abstract MHSRS-23-08562)

Blast overpressure (BOP), also called high energy impulse noise, refers to the sudden and intense increase in pressure due to an explosion. The overpressure generated by the shockwave can result in serious injury or death to nearby personnel and can also cause significant structural damage. In recent years, there has been a growing interest in using capacitive pressure sensors, due to their potential to provide real-time, accurate data that can be used to improve the safety and security of personnel and infrastructure in high-risk environments. In addition to their versatility, flexible capacitive pressure sensors also offer several other benefits, including improved sensitivity, fast response time, and ease of integration into flexible structures. These features make them a valuable tool for a wide range of applications in fields such as healthcare, industrial process control, and environmental monitoring. Given that the experimental methods for optimizing design parameters is complex and time-consuming, the development of analytical methods for optimization is necessary to efficiently obtain the most effective design parameters in various conditions.

We semi-analytically investigate the capability and optimization of a novel flexible capacitive pressure sensor integrated into bendable structures. The proposed sensor is highly tunable and capable of accurately measuring high-pressure and providing real-time feedback, making it a valuable tool for blast-related research and safety applications. This study examines the sensor's performance under different boundary conditions and explores various optimization techniques to enhance its sensitivity, accuracy, and reliability. The results demonstrate the effectiveness of the sensor in measuring blast pressure and highlight its potential for broader use in wearable sensor technology for real-time monitoring and early detection of polytraumatic and traumatic brain injury (TBI).

Our flexible coplanar capacitive sensor is composed of driving electrodes, sensing electrodes, a soft dielectric composite substrate and a conductive or isolated backplane for different boundary conditions. To design and optimize sensors for blast overpressure measurement, several important factors must be considered, including sensitivity, response time, stability over a range of temperatures, and overall durability. This section presents numerical examples to provide an understanding of the behavior of coplanar capacitive sensors, taking into account various parameters such as the gap between adjacent fingers on capacitance, width and thickness of electrodes, penetration depth, location of the enriched layer, and permittivity of soft laminates under different voltage boundary conditions on the sensitivity of the proposed sensor.

Our goal is to leverage the findings of this research to fabricate flexible coplanar pressure sensors using a multilayered soft and stretchy dielectric composite via printing techniques. Additionally, the deformable elastomers can be fabricated using 3D printing techniques. These techniques will allow for light weight fabrication, ultimately allowing for highly wearable sensors that could cover large areas. In future work, these sensors will be directly integrated into combat helmets to provide directional overpressure data in proximity to the head. Through these direct measurements, we can gain insight into overpressure loads experienced in a variety of scenarios. The insight gained from our sensors will contribute to the development of more effective protective gear, leading to a reduction in both the incidence and severity of blast exposure-related polytrauma and physiological changes.

Supported in part by ONR N00014-21-1-2851
Funded PI: Dr. Joseph Andrews, University of Wisconsin – Madison
Managing Program Officer: Dr. Tim Bentley, Naval Force Health Protection Program

Hemodynamic Monitoring via Sequential Inference for Safety Assurance of Physiological Closed-Loop Controllers: Fluid Resuscitation and IV Sedation Case Study

POSTER #278

Poster Presentation by Dr. Jin Oh Hahn (Abstract MHSRS-23-08171)

Motivated by the recent findings that critical care treatments may be automated by closed-loop control algorithms to assist clinicians with important yet tedious patient monitoring and titration tasks, there is an increasing interest in the development of closed-loop control systems to enable critical care automation, including fluid resuscitation, vasopressor administration, anesthesia and analgesia, and mechanical ventilation to list a few.

Each critical care treatment administered to a patient induces multiple physiological changes in the patient, including intended change as well as undesired side effects. However, most previous work on closed-loop automation of critical care therapy has focused on the intended treatment endpoint while neglecting other multi-faceted aspects of patient responses, which raises concerns related to the safety of closed-loop automation. The situation becomes even more convoluted when multiple closed-loop controlled treatments are to be administered to a patient. For example, fluid resuscitation and intravenous (IV) sedation can interfere with each other in a conflicting way, which can possibly drive a patient to a dangerous physiological state: (i) fluid resuscitation to achieve an arterial blood pressure (BP) target dilutes the sedative drug in the blood and weakens its intended effect, while (ii) IV sedative interrupts fluid resuscitation by lowering BP. For these reasons, although closed-loop controlled fluid resuscitation and IV sedation treatments appear to successfully drive a patient to desired BP and sedation targets, the internal hemodynamics of the patient represented by cardiac output (CO) and systemic vascular resistance (SVR) can often be driven to an unacceptably dangerous state. However, CO and SVR cannot be readily measured in real-world clinical practice. Such a limitation presents opportunities related to online estimation of hemodynamics in a patient receiving critical care therapy.

We investigated the potential of modern sequential inference methods for hemodynamic monitoring in a fluid resuscitation-sedation case study. The novelty of this work is that it is perhaps the first sequential inference based on mathematical patient physiology model for hemodynamic monitoring with routine clinical measurements. Its unique practical strengths include: (i) it does not require arterial BP waveform as in existing pulse-contour CO (PCCO) monitors and (ii) it can estimate CO and SVR with explicit account for the effect of fluid-sedative interferences on the hemodynamics.

We explored extended Kalman filtering (EKF) and several variants of particle filtering (PF), and extended Kalman particle filtering (EKPF) as alternative basis for hemodynamic monitoring. The pilot in silico evaluation of the hemodynamic monitoring using a large number of plausible virtual patients generated using a collective inference algorithm demonstrated that its accuracy is either superior or comparable to PCCO in terms of the limits of agreement and correlation coefficient. In sum, the model-based hemodynamic monitoring via sequential inference can play a meaningful role in enhancing the safety of closed-loop controlled critical care treatments.

Supported in part by ONR 1000018024
Funded PI: Dr. Jin-Oh Hahn, University of Maryland
Managing Program Officer: Dr. Tim Bentley, Naval Force Health Protection Program

Tuesday, 15 August | 1300-1315
BREAKOUT SESSION: Undersea Operational Research Panel

Biomimetic Neural Microtissue for Study of Diving and Submarine-Associated Gas and Atmosphere Effects
Oral Presentation by Dr. Dianne Hoffman-Kim (Abstract MHSRS-23-09168)

Hypoxia is a serious and common concern among military and civilian divers. Hypoxia occurs when the diver is forced to operate in an oxygen-deprived environment, either as a result of ascending too quickly or due to miscalculation in or deviation from the dive plan. Divers experiencing hypoxia can be subject to confusion, cognitive impairment, poor decision-making, unconsciousness, and even death. All of these outcomes present unacceptable danger to the warfighter and mission success. However, the effects of hypoxia on the brain are poorly understood. While the effects of hypoxia on cognitive ability are well characterized, there is a significant gap at the cellular level, due to the complexities of cellular interactions and responses in the brain.

Here we demonstrate the use of three-dimensional (3D) cortical spheroids as a model of hypoxic effect on the brain. Spheroids were sequestered to a hypoxic environment for 24 hours and characterized for cell viability, cellular structural integrity, and neural activity. Spheroids were also reoxygenated for 24 hours to assess recovery potential after hypoxia. We evaluated several different molecular and cellular pathways that have been implicated in hypoxic brain injury. We found a decrease in ATP production, presence of reactive astrocytes, loss of neuronal and capillary network structural integrity, and dysfunction of calcium dynamics after oxygen deprivation with complex responses to reoxygenation. Our results suggest that 3D cortical spheroids reproduce key features of hypoxic injury and can be a useful model for therapeutic and preventative measure screening.

Our model consists of self-assembled, scaffold-free, 3D in vitro cortical spheroids derived from primary postnatal rodent cortex. These spheroids have a cellular composition, tissue stiffness, and cell density similar to what is found in the in vivo cortex. Neurons in these microtissues are electrically active and form synaptic connections. Spheroids also spontaneously form capillary-like networks, composed of endothelial cells, pericytes and astrocytes, surrounding a lumen and associated with tight junctions. The cortical spheroids contain a diverse set of brain cell types, including neurons, astrocytes, microglia, oligodendrocytes, and neural progenitor cells, creating a biomimetic model uniquely positioned to study the effects on not only overall brain health, but on each individual cell type as well.

After Hypoxia (OD) and reoxygenation (OD/R), spheroids were characterized for viability using a dye-based LIVE/DEAD assay with calcein AM for live cells and ethidium homodimer for dead cells, and a more quantitative ATP assay, where we lyse the spheroids and measure their ATP.

In conclusion, we present a 3D in vitro biomimetic neural microtissue - a rodent cortical spheroid – that we have subjected to oxygen deprivation and reoxygenation. This experimental model is highly sensitive to gas and atmospheric changes. It showed effects on whole brain health and distinguished effects on neuronal structure, inflammatory glial cells, neurovasculature, and neural electrical activity. This high throughput model, with its heterogeneous outputs, is also easily adaptable to test multiple variables important to the warfighter, including other gases, pressures, and exertion with repeat conditions. Future work will investigate the impact of these, as well as potential therapeutics and mitigation strategies.

Supported in part by ONR N00014-21-1-2855
Funded PI: Dr. Diane Hoffman-Kim, Brown University
Managing Program Officer: Dr. Tim Bentley, Naval Force Health Protection Program

Tuesday, 15 August | 1330-1345
BREAKOUT SESSION: Medicine and Performance Optimization in the Arctic

Resistance Index of Frostbite as a Predictor for Manual Dexterity Performance in the Cold
Oral Presentation by Dr. Douglas Jones (Abstract MHSRS-23-08635)

Military personnel engaged in cold-weather operations are at increased risk for, dexterity loss and localized cold-injury, particularly in the fingers and hands. Maintaining optimal dexterity in the cold is critical for warfighters given the dependence on hand function for performing field tasks such as weapon handling, equipment operation, and medical care. Previous investigations have established a relationship between cold-induced vasodilation (CIVD) and frostbite risk, wherein those with weaker CID experience greater prevalence of localized cold-injury. CID, a vascular response to cold, is characterized by an oscillatory pattern of vasodilation to increase finger tissue temperature. In 1950, Yoshimura and lida developed the Resistance Index of Frostbite (RIF) score, which combines elements (onset time, minimum and mean finger temperatures) of CIVD to provide one overall RIF score ranging from 3 (weak; increased cold-injury risk) to 9 (strong; decreased cold-injury risk). To date, CID and RIF investigations have focused on the relationship to frostbite, with minimal attention given to dexterity performance. The purpose of this work is to evaluate the relationship between RIF score and dexterity performance to identify persons who are more susceptible to dexterity loss in cold environments.

Findings suggest that RIF score (based on CIVD response) can be used to determine warfighter susceptibility to dexterity loss when hands are exposed to cold. This is critical, as RIF can potentially be used to determine expected performance in the cold among individuals, in addition to its established use for predicting frostbite. Furthermore, these findings indicate that hand immersion in cold water, in combination with PPT performance, may be used to determine frostbite risk, as greater decrements in peg placement following hand immersion in cold water were associated with lower RIF scores and lower mean finger temperatures. Previously, only physiological laboratories with equipment capable of measuring precise finger temperature were able to determine RIF, but these new findings suggest that hand immersion in cold water and PPT performance could be used as a surrogate test to evaluate frostbite risk without the need for sophisticated temperature measurement equipment. Lastly, it should be noted that, despite mean finger temperatures remaining below the dexterity threshold for all RIF groups (i.e., finger temperature < 15°C), RIF score was sensitive enough to detect differences in dexterity loss among the groups. Future work should focus on establishing PPT performance as a surrogate for frostbite risk, as this test can be easily implemented within military units preparing for cold-weather deployment.

Supported in part by ONR N0001423WX02215
Funded PI: Drs. Tim Dunn and Douglas Jones, Naval Health Research Center
Managing Program Officer: LCDR Garrett Morgan, Basic Physiological Sciences Program

Tuesday, 15 August | 1330-1345
BREAKOUT SESSION: Undersea Operational Research Panel

Biochemical, Oxidative and Ventilatory Responses Associated with Hypercapnic Hyperoxia
Oral Presentation by Dr. Luke Belval (MHSRS-23-08190)

During military diving operations, closed-circuit underwater breathing apparatuses which supply increased oxygen (O2) tensions are used to maintain stealth and prevent extended periods of decompression. However, prolonged exposure to hyperoxia can cause central nervous system oxygen toxicity (CNS-OT). Moreover, divers can become hypercapnic (excess CO2) due to increased gas density, CO2 breakthrough in rebreathers, or hypoventilation. Previous studies have suggested that hypercapnia accelerates the risk of CNS-OT; however, the mechanisms and biomarkers associated with the combined effects of hypercapnia and hyperoxia are not well characterized. The purpose of this investigation is to test the hypothesis that hypercapnia and hyperoxia will synergize to increase overall reduction-oxidation status, disrupt acid-base homeostasis, and modulate ventilatory responses.

U.S. Navy-trained divers (N=12) underwent two hours of normobaric gas exposure with varying levels of CO2 (0%, 1.5%, 3%) with either background air or balance O2. We collected venous blood samples before gas exposure and 15 minutes after gas exposure. Collected blood samples were used to determine the change in participants' acid-base balance (pH, pCO2, HCO3). We assessed overall reduction-oxidation status via static oxidation-reduction potential (sORP), which is a ratio of the activity between oxidizers and reducers in the blood. Additionally, during gas exposures five minutes before the two-hour mark, ventilatory responses were collected to determine respiration rate, minute ventilation, and end-tidal CO2 (ETCO2). The change in pH, pCO2, HCO3, and sORP were determined by comparing the baseline values to the values collected 15 minutes post gas exposure. These data and the data from the ventilatory responses were compared using mixed effects models, with the fixed effects being CO2 and O2 and the random effect being participants.

We found no effect of hypercapnia, hyperoxia, or the interaction between effects on the change in pCO2, HCO3, and sORP across gas exposures. We observed a main effect of O2 on the change in pH across trials (O2 vs Air: -0.011, 95% CI: -0.035 to -0.001, F= 5.27, P= 0.03), with no main effect of CO2 or interaction effect. Multiple comparisons revealed that this effect is only observed in conditions without CO2 (0% CO2: -0.028 ± 0.033, P=-0.04; 1.5% CO2: -0.019 ± 0.025, P=0.87; 3.0% CO2: -0.022 ± 0.020, P=0.79). Hypercapnia, hyperoxia, and the interaction between gases did not affect respiration rate; however, we found both CO2 and O2 increased minute ventilation with no interaction effect (CO2: F= 75.50, P<0.01; O2: F= 17.44, P<0.001). Multiple comparisons show that these differences persisted at all levels of O2 and CO2 except 0% CO2 vs. 1.5% CO2 on air background (P=0.07). Expectedly, ETCO2 was affected by hypercapnic trials (0% CO2: 4.57 ± 0.749% CO2; 1.5% CO2: 4.94 ± 0.60% CO2; 3.0% CO2: 5.22 ± 0.53% CO2; F= 17.44, P<0.001). ETCO2 was also affected by hyperoxia (O2 vs Air: -0.88% CO2, 95% CI: 0.44 to 1.33 % CO2, F= 17.38, P= 0.001), however no interaction effects were observed.

Currently, we have not observed effects of hyperoxia, hypercapnia, or the interaction between gases on acid-base homeostasis or reduction-oxidation status. However, air-based gas exposures were associated with a small increase in pH across timepoints in comparison to O2. Both hyperoxia and hypercapnia independently resulted in increased minute ventilation and ETCO2, with no effect on respiration rate. These preliminary results imply that under normobaric conditions, hyperoxia and hypercapnia independently, and not synergistically, affect ventilatory responses with minimal affects to acid-base homeostasis or overall reduction-oxidation status.

Supported in part by ONR N0001423WX00580
Funded PI: Dr. Mahamat I. Babagana, Naval Submarine Medical Research Laboratory
Managing Program Officer: Dr. Sandra Chapman, Undersea Medicine and Performance Program

Traumatic Brain Injury On-a-Chip: A Novel Microfluidic Compression Impact Device for the Real-time Detection of TBI-relevant Biomarkers in Cortical Spheroids
Poster Presentation by Dr. Alexander McGhee (Abstract MHSRS-23-08195)

POSTER
#1

The quest for identifying high-fidelity biomarkers to diagnose traumatic brain injuries (TBIs), in particular, injuries without any outward physical signs as in many primary blast and mild TBIs has remained a formidable challenge in part due to two major hurdles. The first is the well-known peripheral blood dilution effect, whereas brain tissue-produced biomarkers show up in relatively low quantities in the peripheral blood, or saliva, to be accessed via simple point-of-care devices. The second is the lack of a complete resolution of what the native temporal biomarker production profile looks like for endogenous cells in the brain parenchyma following an insult to the brain. This last point is further complicated as the cellular expression of injury-relevant biomarkers, and damage-associated molecular patterns (DAMPS), is most likely dependent on the specific character, i.e., deformation profile, of the particular injury.

To most effectively address the latter two challenges, we developed a unique, fully integrated, single-chip in vitro assay capable of producing traumatic brain injury (TBI) relevant strain and strain rates in a physiologically-relevant, 3D cortical spheroid model of TBI. The novelty of this integrated chip design opens up new possibilities for in-vitro studies of TBI previously unrealizable. Firstly, it allows for in-vitro perfusion cell culture of spheroids, making it more biologically relevant and enabling the collection of injury-specific biomarker production rates on a per-cell basis and in real-time. Secondly, built-in control groups are easily implemented in the chip thanks to its flexible design, which facilitates the comparison of injured and control samples, saving time and resources. Thirdly, in-situ immunostaining, antibody-labeling or lysate extraction of spheroids and media post-injury allows for complete molecular and genetic screening access. Lastly, confocal and multiphoton imaging of spheroids pre and post-TBI can be accomplished over specific time periods, from which injury progression and recovery can be studied. Overall, this novel TBI on a chip model opens up new avenues for the detection, screening and profiling of TBI-relevant biomarkers with unprecedented single cell resolution.

We trap 3D cortical spheroids within a microfluidic device capable of inducing mechanical injury while delivering a continuous perfusion flow of nutrients, and measuring injury-specific soluble biomarker concentrations. After successfully trapping spheroids, strains of 0, 20, 40, and 60% were tested at strain rates of 10, 100, and 1000 s-1 covering the range of expected deformations from both blunt and blast TBIs. Cell viability assays were then performed for each condition to allow a correlation of relative cell death to combinations of cellular injury magnitudes and rates. Measurements of the resulting biomarker concentration for each case is also reported.

We show that our fully integrated and novel TBI on-a-chip platform has the capability of identifying and quantifying soluble and structural TBI-relevant biomarker expression profiles in real-time. Furthermore, this in vitro model allows researchers to visualize changes to cellular morphology via time-lapse multi-photon imaging and on-chip immunostaining. In total, this microfluidic platform allows researchers to probe the biomechanics of TBI at the cellular level by providing quantifiable biomarker expression levels and data on cells' morphological and chemical response due to controlled injury. These data will allow for the enhanced design of many therapeutic technologies meant to diagnose, prevent, and mitigate TBI.

Supported in part by ONR 1000014761
Funded PI: Dr. Christian Franck, University of Wisconsin – Madison
Managing Program Officer: Dr. Tim Bentley, Naval Force Health Protection Program

Computationally Efficient Framework to Quantify Head Kinematics Induced Brain Injury from Open-Field Blast

Poster Presentation by Dr. Manik Bansal (Abstract MHSRS-23-10304)

POSTER #172

Direct or indirect exposure to a blast event is a primary cause of traumatic brain injury (TBI) in the military. Blast events cause injury to the brain through multiple mechanisms: 1) primary injuries from blast pressure waves moving through the head; 2) secondary injuries from flying fragments and debris of the blast; 3) tertiary injuries from the body being thrown or impacting another object (inertial loading); and 4) quaternary injuries that result indirectly, such as from fire, toxins, radiation, etc. This study focuses on tertiary injury. Simulating the tertiary mechanism of blast-induced traumatic brain injury (bTBI) is computationally expensive given the longer time durations that must be modeled (>100 ms). Furthermore, existing studies primarily focus on the effect of peak overpressure magnitude alone and ignore other important blast wave characteristics. We propose a computationally efficient framework with the goal of quantifying the effect of various blast wave characteristics (e.g. peak overpressure, overpressure duration, peak underpressure, etc.) on the risk of head kinematics-induced brain injury. This investigation will help in assessing the risk of tertiary bTBI and provide guidance for defining appropriate safety limits of blast exposure for military personnel.

This study demonstrates a computationally efficient numerical framework to quantify risk of tertiary bTBI. The framework is implemented in three steps: 1) a parametric study is performed to capture head kinematics resulting from a wide range of blast parameters using an elastically-articulated rigid body model (EARB) of the human body, 2) the head kinematics data is then used as an input into a finite element analysis, simulating the head motion from the blast wave using a 3D detailed human head-neck model, 3) an axonal deformation calculation procedure is implemented to quantify neuronal injury in the brain.

The results found in this study show that both peak overpressure magnitude and duration influences the acceleration of the head. Based on strain thresholds of neuronal injury from the literature (18%) and our prior FE modeling work, the predicted brain tissue strains from the head kinematics results of the four different blast scenarios are far below the known thresholds for neuronal injury. The overall head motion is observed to be minimal in this preliminary study using Friedlander waveforms. In future work, we will extend our study to include the effects of other aspects of the blast loading event, such as reflected waves and blast wind. Our next steps include 1) testing the EARB model with different blast waveforms and loading directions (frontal and lateral) and 2) performing high-fidelity finite element simulations on the detailed 3D human neck model to quantify the extent and location of neuronal injury in the brain.

We have developed a computationally efficient framework to incorporate various blast wave characteristics for predicting head kinematics induced neuronal injury in brain tissue. This study will enhance our understanding of the relationship between incident blast wave characteristics, head-kinematics, and the risk of tertiary bTBI. This will help in defining the safety protocols for military personnel against tertiary bTBI.

Supported in part by ONR N00014-21-1-2044
Funded PI: Dr. Rika W Carlsen, Robert Morris University
Managing Program Officer: Dr. Tim Bentley, Naval Force Health Protection Program

POSTER
#197

Development of Optimal Helmet Technology Using of Finite Element Analysis
Poster Presentation Mr. Andrew Bagnoli (Abstract MHSRS-23-10531)

Despite millions of dollars spent on the development of helmet technologies for warfighters, most of that budget is spent on traditional methods of development that is iterative impact tests to design a setup that can pass standard tests. The problem with this traditional development cycle is that it is expensive and time consuming to do each test, which greatly limits the number of test configurations that are possible. Instead, by using Finite Element Analysis (FEA) to simulate drop tests, which allows for many more tests with many more variations, the limiting factors in designing an optimal helmet can be mitigated. The main issue that impedes the use of FEA in these scenarios is the difficulty of developing a computational model that can accurately simulate impact tests at the velocities required by the testing standards. This work overcomes this by leveraging, our new, quantitatively predictive foam material model, which is calibrated using high strain rate data, for use in predictive impact test simulations.

Using the commercial FEA software package Abaqus, a digital replica of a standard test setup used in drop tests was developed, including a helmet with the standard seven pad test setup attached to a Hybrid III head and neck, which can accurately model the materials and geometry used in physical impact tests. The main hurdle in modeling the drop tests is the material behavior of the foam of the helmet, due to its highly nonlinear stress-strain relationship, its highly compressible nature, and it being relatively soft compared to other materials in the helmet and Hybrid III head, leading to high amounts of deformation even at lower impact speeds. We have overcome this issue by developing a new, predictive material model for elastomeric foam materials, which is implemented using a material subroutine in Abaqus. Using the model, many variations of the materials inside and geometry of the helmet can be tested much more quickly and in greater number than would be possible in physical tests. To mimic the physical testing procedure, which is a pass/fail based system based on passing certain benchmarks in the maximum acceleration experienced during the test, one at 120g and another at 300g, an objective function for computational optimization has been constructed similarly, in which the value of the objective function rapidly increases near the benchmark acceleration thresholds.

Once impact simulations of many variations of helmet designs have been run using the FEA model, it is necessary to identify the best performing variation. To come up with a single objective measure of the quality of each helmet design, an objective function is used, which takes input from the acceleration histories of the tests, at three different impact speeds (10ft/s, 14.1ft/s, and 17.3ft/s) and five different impact locations (Crown, Front, Rear, Side, and Nape), and produces a single number output for each helmet variation. After several iterations of this neural network informed search over the parameter space, an optimal 'foam-like' material can is determined.

Using a FEA model, fitted using data from physical drop tests as well as high strain rate experiments on the foam liner materials, accurate predictions of accelerations measured in physical drop tests can be made and then used to perform additional tests more rapidly than would be feasible physically. This enables both an exhaustive search over the combinations of the Team Wendy foams and a search over the full parameter space of 'foam-like' material behaviors. This greater number of tests leads naturally to a neural network-based approach which can produce the best possible configuration of the helmet, based on a standard testing procedure trying to hit certain benchmarks in the maximum acceleration over multiple different speeds and impact locations.

Supported in part by ONR N00014-21-1-2851
Funded PI: Dr. Joseph Andrews, University of Wisconsin – Madison
Managing Program Officer: Dr. Tim Bentley, Naval Force Health Protection Program

POSTER
#373

Context Matters: The Development of Navy-Specific Measures of Destructive Behavior
Poster Presentation by Dr. Nathan Bowling (Abstract N00014-23-1-2309)

Destructive behaviors, such as sexual assault, physical assault, and binge drinking, are common within many workplaces (see Spector et al., 2006). No employer—including the U.S. Navy—is immune to these and other similar behaviors. Unfortunately, the presence of destructive behavior can undermine mission readiness and morale, harm the psychological and physical well-being of victims, and impose financial costs. The effective assessment of these behaviors, therefore, is of critical importance. Ultimately, improved assessment may support future advances in the prediction and prevention of destructive behaviors.

Previous assessment efforts, virtually all of which have occurred within a civilian context, have led to the development of generic, one-size-fits-all measures of destructive behavior (e.g., Bennett & Robinson, 2000). Existing destructive behavior measures, for instance, typically don't assess mishandling of munitions—a behavior that is likely relevant within many Navy communities. The current research will result in the development of new, context-specific measures of destructive behavior that are specifically tailored to the unique needs of four U.S. Navy communities: (a) Explosive Ordnance Disposal (EOD), (b) Maritime Expeditionary Security Group (MESG), (c) Navy Expeditionary Logistics Support Group (NAVELSG), and (d) Naval Construction Group (NCG). This is important because future efforts to predict and prevent destructive behavior will depend on the availability of measures that accurately reflect the destructive behaviors that are commonly present among Navy personnel.

To date, we have completed three Research Phases: Focus Groups (Phase 1), Item Generation (Phase 2), and Subject Matter Expert Evaluations (Phase 3). Each research phase, which we review in the next section, moves us toward our goal of developing destructive behavior measures that are tailored to the specific contexts of four U.S. Navy communities.

Supported in part by ONR N00014-23-1-2309
Funded PI: Dr. Nathan Bowling, University of Central Florida
Managing Program Officer: CDR Jake Norris, Manpower, Personnel, Training and Education Information Sciences Program

Flexible-Hybrid Electronic Circuitry to Enable a Light-Weight Helmet Mounted Head-Kinematic Monitoring System That Detects Potentially Injurious Events

POSTER #322

Poster Presentation by Mr. Jeneel Pravin Kachhadiya (Abstract MHSRS-23-08754)

Over the past decade, more than 400,000 military personnel have reportedly experienced traumatic brain injury (TBI). However, this number may be even higher due to the potential for undetected cases. One of the biggest challenges in diagnosing TBI is the lack of obvious physical symptoms, especially for mild cases of TBI. To address this challenge, there is a need for a quantitative method to detect potentially injurious events in real-time.

It is well known that falls, impacts and direct blows to the head are major causes of TBI. Brain injury can also occur when the head accelerates or decelerates very rapidly, termed whiplash – a commonly observed mechanism for head injury from automotive accidents. All these causes are related to rapid movements of the head, which can be measured using sensors. To measure these linear and angular accelerations, high accuracy sensor systems are required which must be lightweight and minimally intrusive to motivate significant uptake by individual military personnel. To overcome these two challenges, we propose a wearable sensor system that is integrated into the helmet to measure and log these rapid and high accelerations. Moreover, the system's printed or flexible nature enables it to be lightweight and conformable not only to current helmet designs but also to other form factors such as a headband. This versatility allows for a custom fitting system that can be easily modified to suit individual needs. Overall, our proposed wearable sensor system offers a comprehensive solution to address the challenges of diagnosing TBI, and its flexibility and accuracy make it a promising tool for ensuring the safety of military personnel.

Our embedded system successfully logged high-g and low-g data from 8 sensors at the rate of 38,400 data points per second. The accelerometer chips feature an onboard analog-to-digital converter and other data conditioning circuitry, which significantly reduces the power consumption to a range of 80µA to 100µA per sensor. The peak linear accelerations recorded by our system and processed using the AO algorithm closely match the internal IMU sensor values. Our findings highlight the advantages of sensors conformed directly to the head in providing reliable data and insights into impacts.

In summary, our project addresses the need for a reliable and comfortable wearable system for monitoring head impacts and injuries. Our system offers analysis from multiple sensors while minimizing power consumption, as well as real-time data collection for deeper analysis to engineer safer helmets. We emphasize that sensors directly attached to the head form can provide more accurate data on the actual impact experienced inside the head, as compared to sensors placed on helmets. This is because the sensors on helmets may not accurately capture the true impact experienced when the helmet moves independently of the head during an impact. Additionally, the integration of thin, flexible electronics makes the wearable system comfortable and unobtrusive to ensure continuous, long term and accurate data collection.

By leveraging the power of flexible and wearable sensor technology, we can improve our understanding of brain injuries and take concrete steps towards mitigating their effects. The proposed head sensing system built utilizing flexible hybrid electronics is a crucial step towards creating a smart wearable that will eventually help prevent long-term traumatic brain injuries.

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Funded PI: Dr. Joseph Andrews, University of Wisconsin – Madison
Managing Program Officer: Dr. Tim Bentley, Naval Force Health Protection Program

Head Sensor System for Determining the Acceleration Field of Occupants in a Fuselage Drop Test
Poster Presentation by Mr. Yang Wan (Abstract MHSRS-23-09377)

POSTER
#333

Mild Traumatic Brain Injury (mTBI) is a prevalent injury among military personnel and difficult to diagnose. Mild Traumatic Brain Injuries are caused by violent head motions, commonly from intense blunt impact like military training, special high-speed boat operating, landing of paratroopers, etc. Most mTBI prevention strategies explicitly or implicitly rely on a "brain injury criterion." A brain injury criterion takes some descriptors of the head's motion as input, like the peak translational acceleration and peak angular acceleration, and then yields a prediction for that motion's potential for causing mTBI as the output. We developed a novel wearable head sensor system that utilizes five inertial sensors to obtain the motion descriptors. The sensor houses both a high-g and low-g accelerometer. We call the head sensor system the Accelo-Hat. Associated with the Accelo-Hat, we developed an algorithm to determine the acceleration field of the head using measurements from sensors. To assess the performance of the Accelo-Hat, we used it on several occupants during a fuselage drop test.

The head sensor system utilizes five inertial sensors, including both tri-axial high-g and low-g accelerometers. The high-g accelerometer is capable of capturing accelerations up to 200 g (g= 9.8 m/sec2) with sample rate of 1600 Hz, while the low-g sensor tracks lower intensity movements up to 16 g with sample rate of 1125 Hz.

The head sensor system was deployed on a fuselage drop test to obtain the acceleration field of occupants in the fuselage to estimate the potential injury further. During the drop test a section of the fuselage of a Challenger 601 jet was dropped from a height of 4.26 m (14 ft) to achieve an impact velocity of 9.14 m/sec (30 ft/sec). The test utilized commercial aviation seats and rigid seats for individual occupants, and a rigid litter plate for a supine occupant. The occupants included FAA Hybrid-3 50th percentile male ATD (Anthropomorphic Test Device) and PMHS (Post-Mortem Human Subjects) of equivalent weight and stature. The Accelo-Hat was installed on the head of the ATD seated on a rigid seat, the PMHS seated on a rigid seat, and the supine PMHS.

The AO algorithm is able to predict complete kinematics of the rigid body, including acceleration field, angular velocity, angular acceleration, etc. The AO algorithm uses data exclusively from four accelerometers, rather than from a combination of accelerometers and gyroscopes. For that reason, the proposed AO algorithm does not involve any numerical differentiation of data when predicting accelerations, which is known to greatly amplify measurement noise. For applications where only the magnitude of the acceleration vector is of interest, the algorithm is straightforward, computationally efficient, and does not require computation of angular velocity or orientation. When both the magnitude and direction of acceleration are of interest, the proposed algorithm involves the calculation of the angular velocity and orientation as intermediate steps. The proposed algorithm can be applied to any arrangement of four tri-axial accelerometers as long as they do not lie in the same plane.

Accelo-Hat collected data from five inertial sensors, labeled #1, #2, #3, #4, and #5. The comparison shows that the developed head sensor system is capable of predicting the acceleration field of the occupants' head in the fuselage drop test at arbitrary locations. The accurately predicted kinematics may then be used in brain injury criteria, especially finite-element-based brain injury criteria, to provide a better estimate of a motion's potential for causing injury.

Supported in part by ONR 4720007503
Funded PI: Dr. Haneesh Kesari, Brown University
Managing Program Officer: Dr. Tim Bentley, Naval Force Health Protection Program

Individual Differences in Cognitive Control and Learning Optimal Task Strategies
Poster Presentation by Dr. Jarrod Moss (Abstract MHSRS-23-09751)

POSTER #342

People who learn to perform the same task can often come up with different strategies to complete the task. Even in relatively simple tasks, these different strategies may differ in their effectiveness. One strategy may also transfer better to other similar tasks, leading to the result that some individuals outperform others on a range of similar tasks due to the strategies that they learn and use for a task.

Most theories of strategy selection incorporate a process for learning about the effectiveness of strategies such that people should learn to select the most effective strategy over time if they have this strategy in their repertoire of strategies. Few theories address how the task's mental representation impacts strategy development or the modification of existing strategies. None of these theories address the relationship between individual differences in cognitive abilities and task representation within the context of strategy development.

In the current research, we build on previous results using an association learning task to examine how individual differences in cognitive control impact the task representation and strategies used in the task. In the task, there are two possible representations that can be developed for the stimuli. One of these representations takes advantage of structure in the task so that learning will transfer to a range of similar tasks that share this structure. The other task representation will not lead to transfer. Developing the more transferable task representation is theorized to involve an interaction between working memory resources in the prefrontal cortex and reinforcement learning processes in the basal ganglia.

In addition, cognitive control tasks were used to measure individual differences in how well people can use cognitive resources such as working memory to achieve their goals. Since cognitive control is also strongly related to prefrontal working memory resources and thought to involve reinforcement learning processes in the basal ganglia, our hypothesis was that individual differences in cognitive control would be associated with whether participants developed the transferable task representation or not.

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Funded PI: Dr. Jared Moss, Mississippi State University
Managing Program Officer: CDR Jake Norris, Manpower, Personnel, Training and Education Information Sciences Program

POSTER #215

Can Nonverbal IQ Function as a Predictor of Working Memory Under Different Conditions of Stress?
Poster Presentation by Mr. Leandro Ledesma (MHSRS-23-09471)

Introduction Working memory (WM) helps humans perform everyday goal-orientated activities. It is the ability to temporarily hold information and modify it in accordance with the task at hand. In the military, WM assessments could be useful for determining optimal job placements that best fit the candidate based on their cognitive capabilities. Additionally, stressors, such as physiological or psychological stressors, which are common in a military setting, can influence WM performance, though most likely not to the same degree for each person. While many studies investigate the correlation between WM and other cognitive constructs, such as intelligence (defined by IQ score), few studies have examined how WM and intelligence influence each other under different conditions of stress, and to our knowledge, none have used a virtual reality (VR) environment to do so. In our study, we introduced the N-back task (a test of working memory) in a VR environment to (1) investigate the relationship between WM at baseline and fluid intelligence; (2) identify how different stressors influence WM performance; and (3) assess whether IQ functions as a predictor of WM performance across different stress conditions. We hope that results from this study may further illuminate the relationship between WM and IQ to allow for easier job placement in the military based on performance under various stressors. Materials and Methods Timeline Data collection spanned four testing days (Days 0 – 3) per participant. On the first day (Day 0), we administered a battery of behavioral assessments and a nonverbal IQ test, then placed participants into a VR environment in which they performed a practice version of the N-back task. The following testing days measured their working memory performance under normal conditions (Day 1), after intense exercise (Day 2), and following sleep deprivation (Day 3). Of the current recruitment pool of 23 participants, 11 participants have completed all four days, and there are 10 for whom all data were successfully collected; 5 participants are still in progress. Therefore, our current sample reported for this study is 10, although data collection is ongoing, with a projected sample size of 65 by summer 2023. Assessments Culture Fair Intelligence Test (CFIT), Scale 2 Form B: A non-verbal IQ test comprised of four subtests (series, classification, matrices, conditions) that yields a standardized IQ score with an average of 100. The total time limit for completion of all subtests was 12.5 minutes, though some of our participants were able to finish in less time. N-back: A working memory task that requires participants to recognize when a target stimulus is the same as a stimulus that was seen n trials ago. For our study, we set $n = 2$; therefore, scores on performance were gathered from trials that correctly identified a target stimulus that was seen 2 trials prior while ignoring those that did not (non-targets). The N-back was performed in a VR environment and took approximately an hour to complete. Each session consisted of 40 practice trials and 640 regular trials, 80% non-targets and 20% targets. Stressors Exercise: For Day 2, participants engaged in vigorous aerobic activity for 20 minutes before doing the N-back. They warmed up on an elliptical machine and verbally informed us when they perceived themselves to be at a vigorous exertion rate. Heart rate monitors were used to verify their exertion before the experimenter started a 20-minute timer, and periodic heart rate checks confirmed that the level of exertion remained constant. Sleep deprivation: For Day 3, participants were instructed to stay awake for 24 hours leading up to the testing session. To verify compliance, a Phillips Health Band watch worn by the participants recorded periods of sleep during the 24 hours. Data collection is ongoing; all these preliminary results should be verifiable by August 2023.

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Funded PI: Dr. Elena Grigorenko, University of Houston
Managing Program Officer: CDR Jake Norris, Manpower, Personnel, Training and Education Information Sciences Program

Effects of Operational Fatigue on Attentional Control Performance During Marine Corps Infantry Mountain Warfare Training
Poster Presentation by Dr. Max Smith (Abstract MHSRS-23-08634)

POSTER
#389

The Mountain Exercise (MTX) is a field training exercise Marine Corps Infantry Battalions take part in to promote operational readiness for missions conducted in mountainous and alpine environments. in the final two weeks of MTX (Final Evaluation Exercise; FEX), Marine Battalions are evaluated on their operational performance, which determines whether Battalions are considered effective for conducting mountain warfare missions. Operating in the mountains entails contending with rapid elevation changes, extreme fluctuations in weather and temperature, and navigating difficult terrain, all while maintaining heightened situational awareness. Poor attention control can not only be deleterious to operational performance but can also increase risk of accidents and medical issues. In the field, these initially minor issues can quickly evolve into casualties. Thus, it is imperative Marines maintain an adequate level of attention control despite the physical and psychological fatigue they experience during mountain operations. Laboratory experiments have demonstrated that fatigue due to sleep loss leads to decrements in attention control performance (Whitney et al., 2017). Moreover, field studies designed to simulate combat operations have shown decrements in vigilance, a key process in maintaining attention control (Lieberman et al., 2005.

The aim of this study was to evaluate the relationship between self-reported sleep disturbance scores and attention control task performance at critical intervals during the Marine Corps MTX. We predicted that we would observe decrements in attention control performance after the Mobility phase of MTX, which entails practicing mountain maneuvers in the field for roughly 2 weeks. We further predicted an interaction effect between self-reported sleep disturbance survey results and data collection session, such that sleep disturbance would partially account for attention control performance decrements in addition to the deterioration of sleep during training.

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Funded PI: Drs. Tim Dunn and Douglas Jones, Naval Health Research Center
Managing Program Officer: LCDR Garrett Morgan, Basic Physiological Sciences Program

The Effects of Deafferentation on Pulmonary Function in Rats Exposed to Hyperbaric Oxygen Conditions
Poster Presentation by Dr. Aaron Hall (Abstract MHSRS-23-08946)

POSTER
#425

Supplemental oxygen is often administered to support patient care within the Military Health System, in addition to being administered to military personnel in a variety of operational settings. Prolonged exposure to hyperbaric oxygen at a partial pressure of 0.6 ATA or greater is known to increase the incidence of pulmonary oxygen toxicity (PO2T). This study focuses on the afferent neurons that are responsible for the relay of sensory information from the tissues back to the brainstem to modulate the physiological responses. Our hypothesis was that aberrant signaling of sensory afferent neurons during hyperoxia mediate the changes in pulmonary function associated with PO2T. To evaluate our hypothesis, we exposed rats with intact and ablated sensory afferent neurons to operationally relevant hyperbaric oxygen exposures and then conducted pulmonary function tests.

The general experimental design consisted of intact and deafferented rats exposed to either air or hyperbaric oxygen (HBO) using a 5-day, 1.35-ATA dive exposure. Deafferentation was achieved by capsaicin injection (50 mg/kg) at post-natal day two. A total of 40 rats were randomized into the four groups, ech consisting of 10 rats: (1) intact air, (2) intact HBO, (3) deafferentated air, and (4) deafferentated HBO. Whole body plethysmography (WBP) was utilized for pulmonary function assessment in all groups.

HBO exposure significantly altered 14 of 22 respiratory parameters in intact subjects. Of these parameters, end expiratory pause, minute volume, and tidal volume were significantly altered in denervated subjects when compared to intact controls. Conclusions: Repeated hyperbaric oxygen exposure caused progressive pulmonary function changes in rats. Ablation of sensory neurons altered a subset of the pulmonary function changes and identified which aspects of PO2T may be impacted by sensory afferent signaling.

Supported in part by ONR N0001423WX00581
Funded PI: Dr. Aaron Hall, Naval Medical Research Center
Managing Program Officer: Dr. Sandra Chapman, Undersea Medicine and Performance Program

POSTER
#426

Rapid Serial Visual Presentation: Mechanisms and Effects on Visual Search Performance in Complex Scenes

Poster Presentation Ms. Krystina Diaz (Abstract MHSRS-23-09824)

Maintaining accurate identification of targets (e.g., foreign vessel signals) and non-targets (e.g., innocuous signals) across different search scenes is integral for operational readiness (e.g., radar/sonar monitoring, unmanned vehicle operation). Failure to accurately identify search objects may result in a loss of operational readiness. Despite this, many targets still go missed, necessitating performance enhancement methods that maximize the sensitivity of correct target identifications. Current research suggests that a majority of visual search operators miss targets due to quitting search early or never inspecting the area of the search display that includes the target (“selection errors”). A promising search method to address selection errors is Rapid Serial Visual Presentation (RSVP), which provides greater control of a search area by presenting information serially, in smaller and equal segments, at-fixation, for a fixed amount of time. There has been evidence of RSVP improving target detection, but the mechanisms and decision-making processes behind this benefit in complex scenes (e.g., cluttered maps or scan images) are not well-known. The present work describes four experiments conducted in succession, to elucidate the performance effects and mechanisms behind RSVP-based search. Experiment 1 explores general trends in RSVP-based search performance in complex scenes. Experiment 2 investigates the role of peripheral clutter in RSVP-based performance, and Experiments 3 and 4 examine the role of eye movements in RSVP-based performance.

Supported in part by ONR N0001423WX01094
Funded PI: Dr. Jeff Bolkhovsky, Naval Submarine Medical Research Laboratory
Managing Program Officer: CDR Jake Norris, Manpower, Personnel, Training and Education Information Sciences Program

POSTER
#418

Effects of Hyperoxia and Hypercapnia on Vestibulo-Ocular Reflex
Poster Presentation by Ms. Lucille Papile (Abstract MHSRS-23-08181)

Maintaining situational awareness and spatial orientation during diving operations is integral to warfighter lethality and mission success. However, poor visual cues due to decreased visibility and buoyancy-dependent reductions in somatosensory inputs lead to an increased reliance on the vestibular system to maintain spatial orientation. During special operations diving, commonly inspired gases can cause hypercapnia and/or hyperoxia, which is known to affect the central nervous system. However, it is unknown if hypercapnia or hyperoxia affects the function of the vestibulo-ocular reflex (VOR) and therefore a diver's ability to visually track a target while in motion. The purpose of this study was to test the hypothesis that increasing the level of inspired CO_2 in both normoxic and hyperoxic conditions will alter the VOR during high velocity head rotations.

We measured VOR gain using the video head impulse test (vHIT) on eight U.S. Navy qualified divers prior to and after one hour of exposure while breathing the gas mixture. Over six visits, participants inhaled a mixture of 0%, 1.5%, or 3% CO_2 with a background of either air or balance O_2 (i.e., 97-100% O_2). VOR gain is calculated as the ratio of head velocity and eye velocity for each semicircular canal during high velocity head rotations in three different planes of motion. We compared right and left canal pairs via paired t-tests. We compared the change in gain for each semicircular canal from baseline to one hour of gas exposure using mixed effects models with fixed effects for CO_2 and O_2, and random effects for participants.

Right and left comparisons for each canal pair were different (Lateral: ΔGain=0.12±0.06, p=<.01; Anterior: ΔGain=-0.53±0.20, p=<.01; Posterior: ΔGain=0.47±0.20, p=<.01). As a result, each of the six canals were evaluated separately. For the left lateral semicircular canal, we observed a main effect of O_2 (ΔGain=0.03±0.02, F= 5.29, p=.03) with no observed effects for CO_2 (F= 1.28, p=.29) or interaction between O_2 and CO_2 (F= 1.76, p=.19). For the right lateral semicircular canal, and both right and left anterior and posterior canals, no significant main effects of O_2 or CO_2 were observed, and no interaction effects (O_2 x CO_2) were detected.

The difference in right and left canal gains could be attributed to the tester's dominant hand, the eye used to collect data, the effects of the breathing apparatus on head motion, and/or an interaction of these factors. While a significant effect of O_2 was noted for the left lateral canal, the minor change in gain is not clinically meaningful and does not imply a functional deficit of gaze stabilization in the field. Additionally, as the effect was only noted on the left side, we infer no central effect on the VOR. Although data collection is ongoing, the preliminary small sample results so far imply a negligible effect of normobaric hyperoxia and hypercapnia on VOR.

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Funded PI: Dr. Mahamat I. Babagana, Naval Submarine Medical Research Laboratory
Managing Program Officer: Dr. Sandra Chapman, Undersea Medicine and Performance Program

Dose Response Impact of Carbon Dioxide on Human Glymphatic Function
Poster Presentation by Dr. Rachael Seidler (Abstract MHSRS-23-10054)

POSTER
#427

Divers, high-altitude pilots, and astronauts are exposed to a variety of extreme environmental stressors, including elevated levels of carbon dioxide (CO_2) (i.e., hypercapnia) (Andicochea et al., 2019; Dunworth et al., 2017; Law et al., 2014). CO_2 is a potent vasomodulator, and while hypercapnia increases cerebral blood flow and arterial blood pressure (Battisti-Charbonney, Fisher, & Duffin, 2011), it may negatively influence glymphatic clearance and brain homeostasis. Glymphatic clearance has been implicated as a key determinant of brain health, removing or redistributing metabolic products, inflammatory and immune-mediated molecules, and additional solutes for disposal (Nedergaard & Goldman, 2016). In mouse models, induced hypercapnic environments have revealed a reduction in the glymphatic exchange (Goodman & Iliff, 2020); however, no studies have evaluated this effect in humans.

In the present work, we are evaluating changes within and between participants via multiple MR (T1-3D MPRAGE, T1-SPACE, and T2-FLAIR with high in-plane resolution) sequences while they breathe ambient air (i.e., control (0.04% CO_2)) in one session and one of three acutely elevated (1.0%, 1.5%, or 2.0%) CO_2 gas mixtures (i.e., dose-response effects) in another session under a randomized, counterbalanced order. MR images are acquired immediately before an intravenous injection of a standard gadolinium contrast agent (gadobutrol) and at two additional timepoints (90- and 360-minutes) following contrast administration. Quantifying glymphatic system function is accomplished by measuring contrast-induced brain tissue enhancement via delayed magnetic resonance imaging.

In this ongoing study, we have identified slowed glymphatic function in the parenchymal and nonparenchymal regions of the brain with elevated CO_2. Regions following this pattern preliminarily include the perineural sheath of the optic nerve, parasagittal dura, interpeduncular cistern, and Meckel's cave. Further, we anticipate that the glymphatic exchange and clearance will be slower under the elevated CO_2 conditions following a dose-response fashion and will be prepared to disseminate these findings further.

In this presentation, I will share a more comprehensive view of our novel results and further elaborate on the potential implications of this research.

Supported in part by ONR N000142012463
Funded PI: Dr. Dawn Kernagis, Florida Institute for Human and Machine Cognition
Managing Program Officer: Dr. Sandra Chapman, Undersea Medicine and Performance Program

Tuesday, 15 August | 1345-1400
BREAKOUT SESSION: Undersea Operational Research Panel

Analysis of Breath Based Volatile Organic Compounds for Prediction of Pulmonary Oxygen Toxicity in Divers
Oral Presentation by Dr. Alan Metelko (Abstract MHSRS-23-08861)

Pulmonary oxygen toxicity limits operational use of enriched oxygen (pO2 >0.5ATA) breathing gas mixtures during diving operations and recompression treatment. Currently, pulmonary oxygen toxicity is avoided by minimizing exposure to enriched oxygen atmospheres. This is accomplished by utilization of a metric referred to as the Unit Pulmonary Toxic Dose (UPTD), which gives a population-based probability of a decrease in vital capacity based on time and partial pressure of inspired oxygen. Unfortunately, there is a very large individual variance in the onset of pulmonary oxygen toxicity symptoms at a given UPTD. The objective of the current study was to evaluate whether volatile organic compound (VOC) based breath biomarkers could allow for accurate individualized prediction of pulmonary oxygen toxicity symptom onset using human breath samples collected during hyperoxic diving studies at the U.S. Naval Submarine Medical Research Laboratory (NSMRL) and the U.S. Navy Experimental Diving Unit (NEDU).

The NSMRL dives involved 14 subjects breathing nitrox (0.61 ATA O2) or 100% O2 in a hyperbaric chamber at 2 ATA for 6.5 hours. The NEDU RIP dives involved subjects breathing 100% O2 (n= 12) or air (n=15) for 6 hours while immersed at 1.35 ATA. The NEDU RIPX dives involved 20 subjects breathing 100% O2 for 6 hours while immersed at 1.35 ATA. Pre- and post-dive breath samples were collected into 1 L ALTEF bags and drawn onto Tenax TA thermal desorption tubes using a MultiRAE pump. The samples were then shipped to the 711th Human Performance Wing for 1-D gas chromatography-mass spectrometry (GC-MS) analysis using a GC-MS detector coupled to a Markes thermal desorption system. Raw chromatogram files were converted to CDF files using Xcalibur and aligned using XCMS. The difference of integrated signal for breath and air (background) yielded a VOC matrix which was normalized and adjusted using internal standards and ambient background samples respectively. A weighted digital analysis model was built using UPTD, and eight predictive VOCs using R 4.2.1 and GraphPad Prism 8.

Incorporating pre-dive VOC data into the UPTD algorithm increased the accuracy of the model from (AUC = 0.86, Accuracy = 0.82, VOC without UPTD) to (AUC = 0.94, Accuracy = 0.90 VOC with UPTD) to identify subjects who presented symptoms prior to oxygen exposure. This improvement in the prediction was statistically significant (p<.0001) as determined using the likelihood ratio test in GraphPad Prism. When the VOC model was tested using the NEDU RIPX data as the test set, the AUC was .88 and the accuracy was .83.

Incorporation of VOCs significantly improved the prediction of symptom onset when compared to the current standard (UPTD alone). Future work to confirm and build on these findings is required prior to transition of this technology.

Supported in part by ONR N0001417WX00936
Funded PI: Dr. Aaron Hall, Naval Medical Research Center
Managing Program Officer: Dr. Sandra Chapman, Undersea Medicine and Performance Program

Tuesday, 15 August | 1400-1415
BREAKOUT SESSION: Medicine and Performance Optimization in the Arctic

Predicting Postural Stability from Skin Temperature After Cold Water Immersion in Field Conditions
Oral Presentation by Dr. Amy Silder (Abstract MHSRS-23-08627)

Service members operating and training in cold environments are exposed to unique challenges. For example, a river crossing or accidental cold-water immersion can significantly impair operational performance and, in severe cases, may require life saving measures. Yet, unlike during similar civilian exposures, the need to engage with hostile forces, move location, or conduct necessary reconnaissance may prevent the warfighter from engaging in optimal recovery. An understanding of the body's physiological and physical response to extreme cold can mitigate the negative consequences associated with cold stress, expedite recovery, and increase safety. While numerous studies have investigated the effects of skin temperature and cold-induced shivering on upper extremity dexterity, fewer studies have considered the effects of cold exposure on balance and lower extremity function.

Extreme cold will cause the body to shunt blood from the extremities, thereby lowering muscular temperature and reducing plantar sensation. As skin temperature drops, nerve conduction velocity slows and motor unit firing rates decrease. The muscles involved in maintaining postural stability utilize primarily the low threshold motor units found in slow twitch muse fibers. For example, the soles is often considered the most important muscle involved in maintaining postural stability and is comprised of primarily slow twitch muse fibers, whereas the vasts lateralis is known for its explosive power and is comprised of primarily fast twitch muscle fibers. One study investigated how soles and the vasts lateralis muscular performance was affected by a 6-hour total body cold water immersion in experienced military divers. Despite reductions in skin temperature at both locations, only the soles muscle demonstrated reductions in maximal and submaximal function. Reduced sensation, decreased neuromuscular control, and vigorous shivering can negatively affect an individual's proprioception and balance.

The primary purpose of this study was to explore the relationship between body temperature and postural stability following whole body cold-water immersion. We hypothesized that thigh and foot temperature would be highly predictive of worse postural stability, and that improvement in lower extremity temperature would be highly correlated with improved postural stability after rewarming.

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Funded PI: Drs. Tim Dunn and Douglas Jones, Naval Health Research Center
Managing Program Officer: LCDR Garrett Morgan, Basic Physiological Sciences Program

Tuesday, 15 August | 1445-1500
BREAKOUT SESSION: Undersea Operational Research Panel

Understanding Unmanned Maritime Systems (UMS) Operator Training
Oral Presentation by Mr. Brandon Schrom (Abstract MHSRS-23-09299)

The Navy's push for an unmanned future not only requires advancements in unmanned vehicles but also advancements in understanding their human operators. Unmanned Maritime Systems (UMS) operators are a part of U.S. Navy Explosive Ordnance Disposal (EOD) Mobile Units, with platoons varying in size and ratings. UMS operators play a crucial role in the Navy's expeditionary forces, providing mine countermeasure support for the fleet by using unmanned underwater vehicles (UUVs) to scan the ocean floor for mine-like objects that could pose a threat to our fleet. Operators are further tasked with operations in varying sea states and weather conditions at any time during the day or night, providing force protection and performing post mission analysis (PMA) of sonar data aimed to inform the fleet or other operating partners of mine-like objects. This study aimed to follow UMS operators in a very intensive training environment during an advanced training cycle while gathering observational data on operations, classroom performance, PMA performance, and mission planning/execution. Moreover, sleep and fatigue metrics were collected to further understand aspects of fatigue resilience in UMS platoons.

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Managing Program Officer: CDR Jake Norris, Manpower, Personnel, Training and Education Information Sciences Program

POSTER
#334

Incapacitation Prediction for Readiness in Expeditionary Domains: An Integrated Computational Tool (I-PREDICT) - A probabilistic investigation of Behind Armor Blunt Trauma (BABT)
Poster Presentation by Dr. Vivek Kote (Abstract MHSRS-23-09716)

Computational modeling is a powerful and widely implemented tool for the analysis of biomechanical systems. Advancements in computational power and software capabilities have allowed researchers to create high-fidelity human body models (HBMs) capable of modeling the body's response to complex dynamic boundary conditions. These models provide advantages when compared to more traditional experimental methodologies, as it is often difficult and costly to perform cadaver experiments for all potential boundary conditions of interest. With all of their advantages, however, computational models still have their caveats. One is the fact that a deterministic model only represents a single individual and cannot accurately predict the risk of injury across a specific population group. Across the human population there is a great deal of natural variation in environmental loading conditions, mechanical tissue properties, and anatomical morphology. For example, biological material properties can have coefficients of variation (COV) of 80% or higher and these material properties play a critical role in determining whether a response was injurious or not. Additionally, the overall size of the subject as well as less obvious anatomical differences can have significant effects on the response and corresponding injury prediction. Exercising a computational model within a probabilistic framework helps to overcome these deficits and allows the model to account for these inherent variabilities. Rather than reporting an injury vs. no injury using a deterministic model, the probabilistic model will directly return a probability of injury relevant to the population of study. As such, the main goal of the I-PREDICT program is to create a precise and validated probabilistic finite element model of the full human body that can be used to predict and evaluate the risk of injury and functional incapacitation in various military environments. One particular use case for a full human body model is to evaluate non-penetrating injuries from blunt trauma due to deformation of the back face of body armor. In this study, the probabilistic I-PREDICT HBM was used to evaluate the injury risk of BABT for three anterior torso impact locations using impact energies derived from clay-test standards used for certifying body armor. We hypothesized that injury risk profiles obtained from the I-PREDICT HBM would not agree with clay-testing standards of acceptability. Moreover, we demonstrated the usefulness of a full human body model to assess injury risk and the detailed information obtainable therein.

To date, three anterior torso impact sites have been analyzed – BABT impacts over the liver, heart, and lower abdomen. Using a hierarchical approach to injury prediction, probabilities of Military Combat Injury Scale (MCIS) injuries for each organ were reported, as well as an aggregate incapacitation score defined by the New Injury Severity Score (NISS). For NISS scores greater than 15, severe injury or death may occur.

Currently, the I-PREDICT team has begun developing a custom process to readily morph the I-PREDICT HBM to different anthropometries for digital twin applications, as well as develop a statistical representation of anatomical morphology that may be implemented as a random variable into the probabilistic analysis. As such, future analyses will incorporate different body shapes and gender in the set of available I-PREDICT finite element models. Additional sets of probabilistic simulations will be performed to analyze the risk of injury at different impact sites, covering the torso and abdomen.

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Funded PI: Dr. Daniel Nicolella, South-West Research Institute
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Towards a Fully Automated Workflow for Subject-Specific Human Digital Twins for Traumatic Brain Injury Risk Assessment

POSTER #336

Poster Presentation by Dr. Anu Tripathi (Abstract MHSRS-23-09939)

Large inter-subject variability in the types and severity of traumatic brain injury (TBI) calls for personalized injury prediction. Thus, the computational models used for injury risk prediction need to capture the unique subject-specific anatomy of the head. The complex anatomy of the brain and currently available tools makes model generation directly from medical images a time-consuming process requiring extensive manual intervention and multiple steps. Some workflows, such as mesh-morphing, have been proposed for faster model generation. However, these workflows have limitations in terms of mesh quality and correlation between the mesh and patient medical scans.

The lack of availability of fully-automated workflows to generate high quality subject-specific finite element (FE) mesh head models directly from medical images has prevented patient-specific TBI assessment. This study aims to demonstrate a fully-automated subject-specific FE modeling workflow from magnetic resonance imaging (MRIs) scans, enabling the automatic creation of human digital twins (HDT). The minimum amount of anatomical details required in the model to capture the underlying mechanism of TBI and to optimize the simulation time will also be explored. These HDTs can be used to assess the risk of TBI for military operational tasks and to inform the design of protective equipment. In our study, we initially leverage two open access repositories of human head MRIs, namely IXI and SCI datasets, to test the efficacy of our approach. In brief, the IXI dataset contains nearly 600 MRI from normal and healthy subjects while the SCI head model contains data from a single subject with accompanying ground truth segmentation information.

We are working towards developing a fully-automated workflow for subject specific FE head model generation. The current efforts are directed at developing and demonstrating the workflow first for a simplified head model. Level of anatomical details will be improved in future iterations of the workflow. We created an open-source code repository, named Autotwin, hosted on GitHub, one of the world's largest and most popular way to collaboratively build software (https://github.com/autotwin). The repository provides automated version control, which allows for the quality pedigree of the code to be always improving through automated testing and deployment of the Autotwin software. From the digital human twins created from the MR/CT data, we performed numerical experiments on heads, with input conditions known to cause mTBI. We have assessed the appropriate level of details, such as cortical folds, to be included in a head model using 22 subject-specific finite element head models. The inclusion of cortical folds and the detailed geometry of the folds have a significant effect on the peak magnitude and spatial distribution of brain strain and strain rate. The specific gyri of the cerebral cortex where the peak strain occurred also varies between models. These results highlight the importance of accurately modeling the subject-specific cortical folds in an HDT to predict the location of injury. Our automated workflow aims to capture these anatomical details.

This study extends our previously developed semi-automated workflow (MHSRS 2022) to a fully-automated workflow to create truly subject-specific high-quality FE models directly from the medical images. This lays the ground work for high-fidelity real-time personalized TBI risk assessment for military operations. Furthermore, these models can be used to predict the risk of TBI for a wide range of blunt impact and blast loading conditions, allowing new targeted approaches to be developed to reduce the risk of injury to the warfighter.

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POSTER
#339

Biomechanics of Degradation and Fracture for the Vertebral Endplate
Poster Presentation by Ms. Verushca Labsuchagne (Abstract MHSRS-23-10132)

The human spine provides structure and support for the body and facilitates movement. The unique spinal anatomy includes soft- and hard-tissue structures that work in concert to support different types of mechanical loads. From a load-bearing perspective, the vertebral endplate is a crucial element of the spine that forms the interface between the vertebral body and intervertebral disc. The endplate functions along with the disc to support compressive loads on the spine. As the spine is compressed, the nucleus redistributes compressive loads equally in all directions, pushing outward on the annulus fibrosus and upward/downward on adjacent endplates. As the endplate is physiologically deformed, greater in the central than outer regions, it sustains tensile loads in all directions. Therefore, the endplate supports compressive loads on the spine through its tensile strength and stiffness. Characterizing the tensile stiffness, failure response, and damage response of vertebral endplates, particularly in the lumbar spine which can sustain large compressive loading during physiologic and traumatic events, is essential to better understanding spinal biomechanics, development of scientifically-based safety enhancements or exposure limits, and validation of finite element models (FEM) that can be used to better protect service members exposed to long-duration repetitive lumbar spine compressive loads as a part of their occupational environment.

Across all specimens, the average elastic modulus was 316 MPa (54 MPa SEM) and the average ultimate stress and strain were 9.1 MPa (1.7 MPa SEM) and 3.0% (0.4% SEM) strain. The vertebral endplate is a composite structure by nature, consisting of a cartilaginous endplate layer with low density subchondral bony layer that supports vascular tissue and marrow. Because of this, it is our contention that thicker specimens included a higher percentage of subchondral bone that may have reduced the bulk properties of the specimen during tensile testing.

This study provided important and unique tensile properties for the vertebral endplate. As expected, tensile stiffness and failure properties of the endplate were much lower than cortical and trabecular bone. This demonstrates the susceptibility of the endplate to acute or progressive injury under large single cycle or lower magnitude repetitive compressive loads. From a clinical perspective, this is an important finding due to the role of the endplate in different injury mechanisms as well as intervertebral disc degeneration. Schmorl's nodes are injuries to the endplates that have been associated with low back pain when identified in the lumbar spine. The endplate is also important in the mechanism of vertebral body burst fracture, where the nucleus fractures the endplate under high compressive loads, producing outward bursting of the associated vertebral body. The endplate can also play a critical role in disc degeneration as indicated by medical imaging-identified Modic changes that have been used as a marker for spinal degenerative changes.

Single-cycle tensile elastic and failure properties are important for understanding spinal injury biomechanics and will provide important biomechanical data for FEM used to predict spinal injuries across a variety of loading environments, such as the IPREDICT whole body FEM. Future laboratory-based testing will incorporate other loading modes, such as three/four-point bending, and repetitive sub-failure loading to characterize degradation of endplate material properties associated with loading environments such as whole-body vibration sustained by helicopter aircrew and fast boat crew. These properties can be incorporated into the IPREDICT model to better understand injury and incapacitation, and define more effective design specifications for military personal protective equipment.

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Managing Program Officer: Dr. Tim Bentley, Naval Force Health Protection Program

Influence of Lumbar Spine Orientation on Fracture Characteristics
Oral Presentation by Ms. Rachel Cutlan (Abstract MHSRS-23-10257)

Members of the military are consistently exposed to conditions predisposing them to lumbar spine fractures, such as underbody blasts, helicopter crashes, and aircraft ejections. Multiple studies report that more than half of spinal injuries in military members occur between T12 and L5, and military members see more lumbar spine injuries compared to the general population. The type of lumbar spine fracture depends on the characteristics of the loading environment at the time of injury, such as acceleration, applied force, and alignment of the spine. Understanding the biomechanical factors leading to lumbar fractures in military members can aid in the development of safer technologies which have the potential to decrease the severity of spinal injuries or prevent them altogether. The goal of this analysis was to classify lumbar spine fractures according to the AO spine clinical classification system and determine how the orientation of the spine affected the type of consequent lumbar spine fracture.
For this analysis, 16 specimens were categorized by fracture type: 2 hyperextension fractures, 4 wedge fractures, 7 burst fractures, and 3 chances fractures. All fractures occurred in the upper section of the lumbar spine (T12-L1) except for two of the burst fractures (1 at L2 and 1 at L3) and one of the hyperextension fractures (1 at L2). The orientation of the lumbar spines during test setup, such as Cobb angle, ARA, and tilt, influenced the fracture type. The intra-observer reliability was high, with a coefficient of determination of 0.96. Spines with hyperextension fractures had the largest Cobb angle (45 degrees) and largest ARA (38 degrees), placing the spine in lordosis. Chance fractures occurred in spines in the opposite orientation, typically very flexed and straight, with an average Cobb angle of 17 degrees and the average ARA 16 degrees. Hyperextension fractures were also tilted forward, forming on average a 73-degrees angle with the horizontal. This was a larger tilt than the other fracture type tilt angles (chance = 83 degrees, wedge = 84 degrees, burst = 81 degrees). Hyperextension fractures and chance fractures demonstrated the two extremes in spine orientation regarding flexion and extension.

Wedge and burst fractured spines did not appear to have differences in Cobb angle or ARA before loading. Wedge fractures saw higher average peak force and acceleration values (7080 N, 55.9g) than burst fractures occurring at L1 (4890 N, 15.6g). Comparing wedge and burst fractures that occurred at L1, wedge fracture spines saw a larger horizontal distance between the centroid of L1 and application of the load (0.6 in) compared to burst fracture spines (0.4 in). Wedge fractures also occurred in vertebrae that were anteriorly rotated compared to burst fractures at the same level.

There was also evidence of a level dependent factor of orientation. A hyperextension fracture occurred at L1 and L2. The fracture at L1 resulted from a smaller force (3930 N) than the fracture at L2 (4812 N). Pre-loading orientation of the L1 fractured spine was in extension compared to the L2 fractured spine.

The orientation of the lumbar spine affects the resulting fracture type. These results further contribute towards understanding biomechanical factors in lumbar spine injuries. Moreover, this analysis shows that the position of the military member at time of aircraft ejection or aircraft crash can influence the type of resulting lumbar spine injuries. Ultimately, the findings of this research can be translated to military members through the identification of strategies and practical training of naval aviators in spinal positioning prior to aircraft ejection and the development of technology targeting spinal orientation maintenance in crashes, underbody blast, blunt trauma, etc. These are results that will be expanded on and further analyzed to assess bone mineral density for each specimen and the role it may play in influencing the location of injury, type of injury, and tolerance to injury.

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Funded PI: Dr. Brian Stemper, Medical College of Wisconsin
Managing Program Officer: Dr. Tim Bentley, Naval Force Health Protection Program

Wednesday, 16 August | 1615-1630
BREAKOUT SESSION: Military Injury Biomechanics and Applications for Injury Prevention

Thoracic Deformation Under Backface Impact in Hard Body Armor: Clay vs Human Cadaver
Oral Presentation by Mr. Derek Pang (Abstract MHSRS-23-09528)

Current body armor testing methodologies for the prevention of behind armor blunt trauma (BABT) utilize an oil/wax-based Roma Plastilina #1 (RP-1) clay as a human tissue surrogate with a 44mm threshold for armor back-face deformation. This standard was created to provide a rapid, inexpensive alternative to ballistic gelatin for VIP soft body armor. This addressed wounding potential from a class of handgun threats in the 1970s while avoiding complex ballistic gelatine analyses requiring high-speed film to determine maximum deformation depth [1]. The clay standard was based on a nonfatal 45kg goat model with a 38 Special threat loading soft body armor. The methodology assumes that the residual deformation in RP-1 is equal to the maximum deformation. Since that time RP-1 clay composition has changed making it stiffer and requiring testing at elevated temperature [2]. More importantly, the handgun assessment is now used for rifle rounds into hard body armor, well outside the conditions for which it was designed. This study assesses backface response of human cadaver torso compared with clay deformations in the context of hard armor BABT injury risk.

A substantial amount of “tapering” or “bulging” is noted towards the edges of the deformation profile in cadaver when compared to the profile in clay. This adds to the larger amount of armor area recruited relative to clay, preventing excessive deformation depth, but is influential on determining area impacted by the back face. Being that the plate’s X-axis was rendered at the minima of positive deviation from the back face, the area represented at the axis may not be representative of the actual area. Thus, further comparisons were performed for areas at 10% and 50% of the maximum deformation depth. In clay, deformation characteristics are obtained from residual deformations, which may not be wholly representative of the true deformation in clay. In later testing utilizing polycarbonate indenters to simulate the impinging face of an armor plate on clay, cadaver, and porcine models, clay possessed a tendency for “rebound” as clay at peak depth returns to residual levels over time.

Further differences between the cadaver and clay include the profiles in the clay being generally more concentrated and deeper at the maximum depth (pointed). This may be due to the presence of ribs spreading the load across more armor surface to prevent deeper penetration, indicating that the lack of structural anatomy in the homogenous clay may be a critical limitation given a fixed depth threshold for evaluation of hard armor. Analysis of cadaver injury scores and deformation geometry indicates that injuries of different severity may be related to impact placement more than deformation characteristics. In the cadaver test series, an impact to the spine was recorded at 700m/s with considerably injurious results (AIS5) despite deformation geometry and velocities at similar or lesser values than other impacts. This suggests geometric considerations alone may not be an accurate evaluation for preventing BABT.

This quantitative comparison of deformation profile geometric characteristics in RP-1 clay tests and cadaver models act in conjunction with the qualitative reassessment of injuries seen in cadaver models to provide evidence that the RP-1 clay model and residual deformation depth threshold standard used in current armor evaluative standards do not represent of hard armor BABT. RP-1’s lack of structural anatomy and material characteristics contribute to large differences with the cadaver model in hard armor back face deformation depths, volumes, areas, and the energy inputs to achieve similar results. These factors indicate a present demand for more accurate test methodologies to optimize armor weight and protection against BABT in future hard armor designs.

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Managing Program Officer: Dr. Tim Bentley, Naval Force Health Protection Program

Wednesday, 16 August | 1630-1645
BREAKOUT SESSION: Military Injury Biomechanics and Applications for Injury Prevention

Development of a 50th Percentile Male Warfighter Model for Incapacitation Prediction in Behind Armor Blunt Trauma

Oral Presentation by Dr. Zachary Hostetler (Abstract MHSRS-23-10474)

When body armor defeats an incoming projectile, a large amount of energy is transferred from the armor to the chest. This high-rate loading can cause serious injury and even death. The modern warfighter is equipped with an advanced suite of personal protective equipment (PPE) to combat behind armor blunt trauma (BABT) injuries. However, there is a lack of suitable and easily accessible human surrogates for designing PPE countermeasures for BABT testing purposes. Digital engineering tools are poised to fill gaps in the design process and facilitate both expedited and more comprehensive design analyses. One of the goals of the Incapacitation Prediction for Readiness in Expeditionary Domains: an Integrated Computational Tool (I-PREDICT) is to create a human body model (HBM) to better understand BABT injury mechanisms and fill the gap in the experimental testing procedures. The goal of the I-PREDICT HBM is to predict injury and functional incapacitation for various in theater military applications.

A series of 7 whole body impacts to the torso were conducted. An oblique chest impact and frontal impact based on Viano et al. and Kroell et al. respectively were conducted with an impactor mass of 23.4 kg and an impact velocity of 6.7 m/s. The resulting force-deflection response was compared to experimental data. Additionally, an abdominal impact based on Hardy et al. was simulated where a 48 kg bar impacts the abdomen at 6 m/s and the force compression response was compared to experimental data.

The I-PREDICT HBM v0.4 consists of 2.3 million elements and 1.4 million nodes. Element quality was checked to ensure less than 1% of the total number of elements exceeded thresholds for warping, aspect ratio, and skewness. No elements violated the threshold for Jacobian elements.

The I-PREDICT model was stable in all 17 validation cases. Energy balances were checked to ensure additional energy was not added to the system and added mass was <1% for all simulations. The average CORA score for component level simulations was 0.81 ± 0.16 with a range of 0.44 to 0.98. The CORA scores for the Viano et al. and Kroell et al. experiments were 0.79 and 0.80 respectively.

The BABT simulations consisted of comparison to both injurious and non-injurious experiments. For the liver BABT loading condition the model predicted an 83% chance of fracture on right rib 6 and 100% chance of rib fracture in rib 7, demonstrating excellent agreement with the experimental data as rib fractures were observed in both ribs 6 and 7. For the heart BABT impact, the PMHS suffered rib fractures left 2-4. In this case, the model moderately under predicted fracture in ribs 2 (42% risk) and 3 (8% risk), with less than 1% risk for rib 4. No rib fractures were observed in the experiment for the right upper lung impact and the model predicted no risk of injury. A limitation for this comparison is that the experimental sample size for each impact location was N=1.

This work has successfully demonstrated the ability of the I-PREDICT HBM to simulate BABT and predict human response. Quantitative evaluation of the model indicated good agreement with experimental PMHS data. This effort lays the groundwork for the I-PREDICT HBM to be integrated into a probabilistic framework for advanced validation and evaluation of PPE designs for a broad range of the warfighter population. The I-PREDICT HBM can be used as a digital design tool to fill the experimental design gap for BABT and aid in protection for military personnel in various environments.

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Funded PI: Dr. Matthew Davis, Elemance
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Investigating Cavitation-Induced Primary Injury during Open-Field Blast to Determine Safety Limits for the Warfighter

Oral Presentation by Dr. Manik Bansal (Abstract MHSRS-23-10243)

Blast-induced traumatic brain injury (bTBI) is the most common and concerning injury in the ongoing era of asymmetric warfare. The nature of bTBI is very complex and various mechanical injury mechanisms have been proposed such as direct cranial transmission of blast waves, skull flexure, inertial loading, and thoracic surge. Cavitation, i.e., the formation of cavities due to high tension (negative pressure), is also a potential blast-induced injury mechanism. While existing literature provides blast safety limits for various internal organs (upper respiratory tract, lungs, and gastrointestinal), safe exposure limits for bTBI are currently based on blast overpressure alone and do not consider other important characteristics of the blast wave. Our aim is to study the effect of various blast wave characteristics (e.g., peak overpressure, overpressure duration, peak underpressure, etc.) on the risk of cavitation-induced neuronal injury, considering blast wave intensities ranging from low (military training with heavy weapon systems) to high (explosions in combat scenarios). This investigation will help in assessing the risk of bTBI in military training exercises and operational environments, providing critical guidance to maintain the safety of military personnel.

A novel numerical framework is developed to define bTBI safety limits by investigating the relationship between open-field blast wave parameters and cavitation-induced neuronal damage. The framework is composed of three main steps: 1) parametric study is performed to capture high-resolution intracranial pressure (ICP) field for a detailed 3D human head-neck finite element model by varying underlying parameters of blast waves, 2) an experimentally validated bubble growth model is implemented to estimate the maximum growth of cavitation bubbles by considering high-resolution ICP field data as an input, and 3) the expected neuronal injury is determined based on recently conducted in-vitro experiments relating maximum bubble size to neuronal injury.

For our preliminary study, we considered an experimental ICP (peak negative gauge pressure equal to -151 kPa with negative phase duration of 0.4 ms) induced by the frontal blast (peak overpressure of 85 kPa with duration of 3 ms) and measured at the occipital lobe of an ellipsoidal surrogate head model filled with Sylgard gel. The cavitation growth is modeled for stiff and soft brain tissue (density of 1040 kg/cubic m) with shear modulus equal to 19.1 kPa and 7.0 kPa, respectively. The mechanical behavior of both stiff and soft brain tissue is modeled using a non-linear Neo-Hookean Kelvin-Voigt material model with a viscosity equal to 88 mPa.s and 395 mPa.s, respectively. The cavitation models predict explosive bubble growth at an equilibrium bubble radius of 20 micrometers for both stiff and soft brain tissue. The size of the cavitation bubble grows by 5.6 times in the stiff brain tissue and 7 times in the soft brain tissue, indicating potential to damage 50% of neuronal tissue by volume in the vicinity of the bubble based on our experimental study. Our next step is to quantify the relationship between blast wave characteristics and the risk of cavitation-induced neuronal brain injury.

We developed a high-fidelity numerical framework with a capability to incorporate various blast wave characteristics for quantifying cavitation-induced neuronal injury in brain tissue. This study will enhance our understanding by identifying the relationship between incident blast wave parameters, cavitation bubble size, and risk of bTBI. This helps in defining safety protocols for military personnel against cavitation-induced bTBI.

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