

NAVAL SCIENCE AND TECHNOLOGY FUTURE FORCE™

FALL 2017

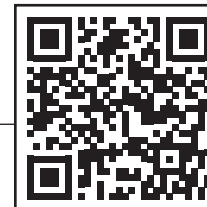
UNDERSEA MEDICINE

DOING MEDICAL
RESEARCH WITH
"THE KRAKEN"

MODERN TOOLS FOR
MODERN MEDICAL
PLANNING



NAVAL MEDICAL
AND
HEALTH RESEARCH



IN THIS ISSUE ▼

- | | | | |
|---|----|----|--|
| Speaking of S&T
Naval Medical and Health Research | 04 | 16 | Modern Tools for Modern Medical Planning |
| Plenty of Room at the Bottom: Making Undersea
Medicine a National Naval Responsibility | 06 | 24 | The Navy's Oldest Certified Dive Chamber Still
Heals under Pressure |
| Finding Solutions for Physiological
Episodes in Naval Aviation | 12 | 30 | The Little Lab that Could |

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20 Research in Special Environments at the University at Buffalo

This center in upstate New York has been at the forefront of medical research for those who work both above and below the sea.



28 The Kraken Goes to Battle against Spatial Disorientation

With multiaxis motion control to investigate spatial disorientation, Naval Medical Research Unit-Dayton houses the "Disorientation Research Device"—also known as the Kraken.

Future Force is a professional magazine of the naval science and technology community. Published quarterly by the Office of Naval Research, its purpose is to inform readers about basic and applied research and advanced technology development efforts funded by the Department of the Navy. The mission of this publication is to enhance awareness of the decisive naval capabilities that are being discovered, developed, and demonstrated by scientists and engineers for the Navy, Marine Corps, and nation.

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The Naval Research Enterprise discovers and advances science and technology to improve the health and performance of our fleet and force. These groundbreaking achievements are directly affecting Sailors and Marines afloat and ashore—by improving performance, enhancing resilience, protecting against injury, increasing survivability, as well as evacuating and treating the wounded. Collaborative partnerships between naval-funded researchers and researchers in other government organizations, industry, and academia have a crucial role in achieving our shared goals—addressing naval-relevant medical research to better protect our warfighters.

This issue of Future Force showcases current medical research efforts, highlighting the enduring commitment of the Navy to support warfighter health and performance. From investigating physiological episodes in naval aviation to studying spatial disorientation using a one-of-a-kind research platform, “The Kraken”—it is clear the basic and applied research being performed is of utmost importance to our mission readiness. Also featured in this edition is undersea medicine (a National Naval Responsibility), funded by the Office of Naval Research, the world leader in undersea biomedical investments.

The Office of Naval Research warfighter performance department funds programs focused on the career health and performance of Navy and Marine Corps personnel. The priorities include:

- Protecting health and mitigating risks while expanding undersea operations
- Increasing the survival of casualties through life-saving treatment and stabilization
- Preventing stress-induced injury across a range of naval environments
- Optimizing warfighter training and team dynamics
- Developing synthetic biology tools and biomaterials for future naval applications
- Preventing and treating noise-induced hearing loss.

The Naval Research Enterprise collaborates with partners in the Department of Defense directly or through committees such as the Office of the Secretary Defense’s Reliance 21, Armed Forces Biomedical Research Evaluation and Management committee. International collaborations include those within NATO Human Factors and Medicine panel and in The Technical Cooperation Program Human Resources and Performance group.

By leveraging partnerships and resources, the Naval Research Enterprise will continue to work together to enhance the health and performance of our warfighters by pushing the boundaries on innovation.

Dr. Mason is the department head of the warfighter performance science and technology department of the Office of Naval Research.

Photo by MC1 Ernest R. Scott



Lt. Cmdr. Matthew Stepanovich, an orthopedic surgeon, prepares to make the first incision during a surgical procedure in an operating room aboard the Military Sealift Command hospital ship USNS Comfort (T-AH 20).

NAVAL MEDICAL AND HEALTH RESEARCH

The physical rigors of operating under, on, and above the ocean can be among the most extreme that the human body can experience. Because Sailors and Marines work in these unique environments, the Navy and Marine Corps have long paid special attention to medical and health research that allows warfighters to work in places where the absence or abundance of oxygen and pressure can put human life in peril.

PLENTY OF ROOM AT THE BOTTOM:

Making Undersea Medicine a National Naval Responsibility

By Dr. William R. D'Angelo

WORKING IN THE SEA CARRIES WITH IT EXTRAORDINARY CHALLENGES. THE NAVY HAS MADE IT A SPECIAL MISSION TO SUPPORT RESEARCH THAT HELPS SAILORS SURVIVE—AND EXCEL—IN THIS DIFFICULT ENVIRONMENT.

Humans are not made to live and work underwater. The Office of Naval Research (ONR) Undersea Medicine (UMed) National Naval Responsibility (NNR) comprises the science and technology efforts to overcome human shortfalls in operating in this extreme environment. The two main ways to do this are to enhance human physiology with pharmacological and other therapies, or to provide technology that protects from the environmental challenges. A less attractive option is to set limits on undersea operations. The goal of UMed is to understand and mitigate the basic physiology of exposure to extreme environments. This will allow for an expanded operational envelope (i.e., greater depth and time) for divers and combat swimmers, provide novel solutions for submarine escape, and enhance physical and cognitive undersea human performance.

The warfighting capabilities served by UMed can be thought of in three groups: vertical diving, horizontal diving, and submarine operations. Vertical diving entails both rapid operations involving rescue and recovery as well as a range of sustained operations that could include construction, salvage, husbandry, explosive ordnance disposal, and route clearance. Longer, deeper dives can use the technique of saturation diving, which allows the body to become saturated with breathing gas, thus expanding useful bottom time. Horizontal diving is the foray of naval special warfare and includes combat swimming and operating from SEAL delivery vehicles with a corresponding clandestine requirement. Submarine operations include long missions in confined spaces, crewing, and watchstanding issues as well as the building of the mental models required to make sense of the undersea environment. The capability to operate deeper, longer, safer, and cheaper depends on our ability to develop novel approaches to undersea biomedical issues.

As the physicist Richard Feynman said in his famous lecture on nanotechnology, "There's plenty of room at the bottom." Humans have not taken full advantage of the undersea terrain and will not be able to do so until major breakthroughs have been achieved. In addition, we have incomplete knowledge and understanding of the physiological consequences of exposure to extreme environments. Until we fully explore these reactions at the cellular, molecular, and biochemical level, and before we understand the response pathways involved to a higher degree of complexity, we cannot make these needed breakthroughs.

A global technical awareness study on undersea medicine was undertaken with ONR Global and the medical intelligence community. It demonstrated that ONR is by

Photo by MC2 Sean Furey

far the world leader in undersea medicine biomedical investments, yielding the highest productivity. Our nearest competitors are either frustrated at their lack of investment or hedging their bets on “shotgun” approaches that apply off-the-shelf pharmaceuticals to undersea medicine challenges. While it requires patience and long-term investment, the main tenets of the UMed NNR are to do the difficult work of exploring the basic physiology and, more important, to tie these findings together into coherent complex system descriptions that can be manipulated to enhance undersea performance.

The long-standing physical issue associated with diving has been decompression sickness (DCS), or the “bends,” as it was termed when discovered in 19th-century caisson workers. The body absorbs gas when the pressure is increased and releases it from the tissues when the pressure is relieved. In the most severe circumstances (termed a gas embolism), a gas bubble may become large enough to block a blood vessel and cause a stroke or even death. For the military, DCS came to the forefront in the 1900s when diving capabilities were being developed by the Royal Navy to work on, and rescue, the newly operational submarines. At this time, the first military dive

tables were experimentally derived by physiologist John Scott Haldane in order to set strict limits on bottom times and to require careful decompression procedures to avoid DCS. Unfortunately, times have not changed dramatically in that the Navy still works under similar operational limitations. Diving efforts are hampered by limited bottom times, long decompression times, and the need to have prompt access to large and costly recompression chambers wherever diving will occur.

With the advent of more sophisticated breathing equipment and gas mixtures came the problem of hyperbaric oxygen toxicity. While oxygen generally is good, too much oxygen is actually bad. Hyperoxia can affect the central nervous system, lungs, eyes, and even the muscles. Named for the efforts of two 19th-century scientists, the central nervous system condition is called the Paul Bert effect, and the pulmonary condition the Lorrain Smith effect. In the worst case, hyperoxia can cause a seizure—leading to loss of the mask and drowning. Mitigating seizures, however, then increases the likelihood of pulmonary toxicity. Today, the Navy dives with very strict operational limits to avoid hyperbaric oxygen toxicity. If the solution for oxygen toxicity were found, this would

also provide a new avenue to avoid DCS—with increasing portions of oxygen in the breathing mix, less diluent would be needed, thus reducing the decompression burden.

Contaminated water diving, cold water exposure, nutrition, and hydration are additional challenges common to the extreme underwater environment. These hazards are not limited to the diving community. Submariners escaping from a disabled submarine with a compromised pressure hull will be subject to potentially fatal DCS, embolism, or hyperbaric oxygen toxicity, and a submarine rescue scenario could result in mass DCS casualties that could overwhelm available recompressive treatment assets. Modern advances in biomedical science, including new tools from the fields of immunology, medical imaging, genetics, genomics, proteomics, and pharmacology provide fertile ground for addressing these issues.

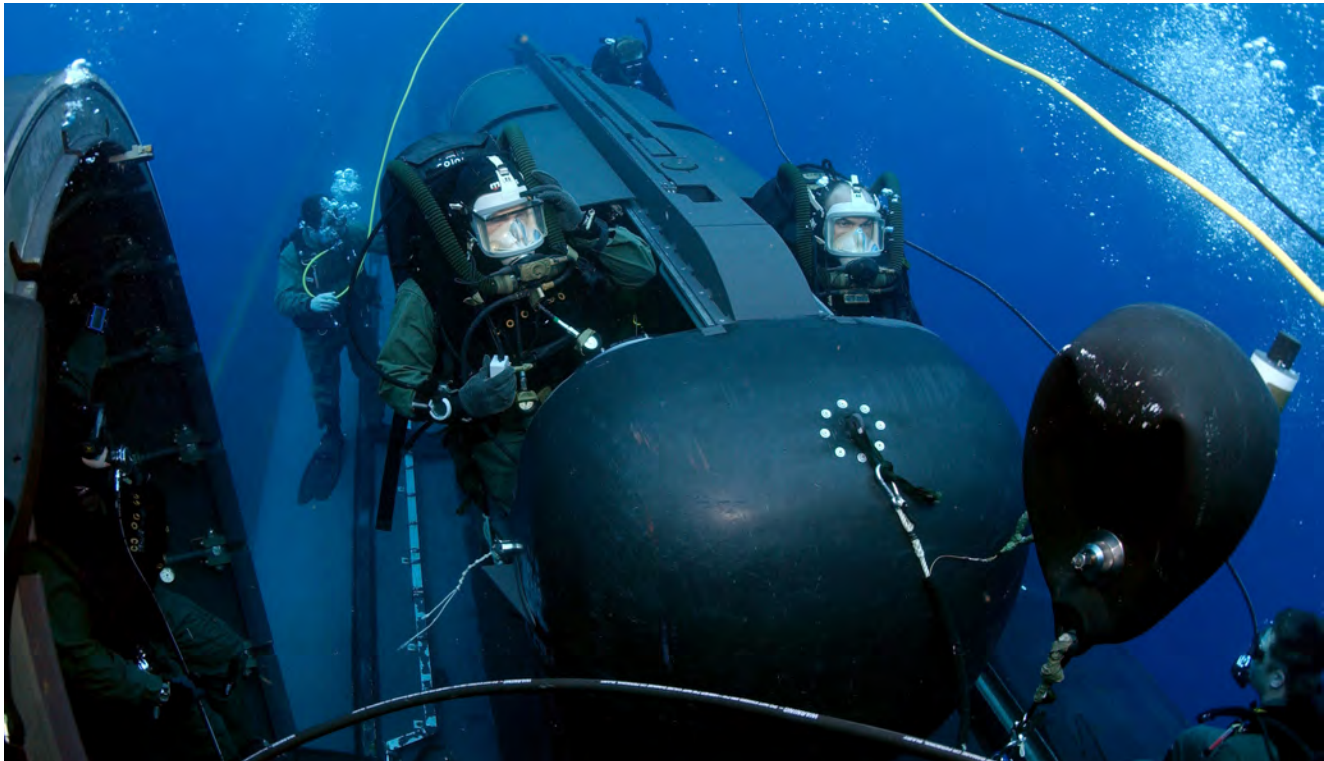
The genesis of the UMed NNR comes from a detailed review and assessment of the health of the existing undersea medicine research program and national capability performed in 2002 by the Undersea and Hyperbaric Medical Society and then-UMed program officer, Cmdr. Stephen C. Ahlers. The subsequent report found that “current funding is no longer sufficient to ensure a viable research program to adequately support the Department of the Navy in maintaining superiority in undersea operations and enhancing the performance and safety of the personnel engaged in these operations.” Other military services, national research agencies, and commercial interests provided only minimal funding for UMed-related research and the number of domestic institutions performing UMed research had declined four-fold. The cadre of scientists who provides national expertise had aged and was not being adequately replaced by younger investigators. The specialized facilities required were disappearing because of initial and life-cycle maintenance costs, the need for specialized support in hyperbaric engineering, and the requirements for safety inspections, space, and diving gases. Recommendations included the commitment by ONR of adequate, stable funding to assure scientific productivity, the training of new investigators, and the maintenance of a critical mass of UMed research facilities.

The case for a UMed NNR was then presented to Chief of Naval Research Rear Adm. William J. Landay by Capt. Charles R. Auker in August 2006. Approval for the NNR was granted three months later. Recommendations included establishing naval officer training for

physiologists, psychologists, and medical officers. It was also recommended to revive the cosponsorship of the triennial symposia in underwater and hyperbaric physiology, plan transition pathways from basic research to acquisition, and stabilize program management by hiring a Navy civilian program officer with an anticipated 8-10-year tenure. It was not recommended to increase annual funding levels at that time. Goals for the nascent NNR included enhancing undersea mission flexibility and efficiency, reducing risks to undersea operators, and decreasing the medical logistical burden.

Since that time, the UMed community remains healthy with the support of a stable NNR program. This community consists of M.D.s, Ph.D.s, engineers, and uniformed researchers. It also comprises the operators and program managers at the warfighting commands, the program offices, the Navy staff, and the Bureau of Medicine. Strong UMed research programs are under way at the Navy laboratories: the Naval Submarine Medical Research Laboratory, the Naval Medical Research Center, the Naval Health Research Center, and the neighboring Navy Experimental Diving Unit and Naval Surface Warfare Center in Panama City, Florida. The NNR supports academic research programs at Case Western Reserve University; Duke University; the State University of New York at Buffalo; the University of California, San Diego; the University of Connecticut; the University of Maryland; the University of Pennsylvania; the University of Southern California; and the University of South Florida, among others.

The NNR supports the Undersea and Hyperbaric Medicine Society meeting and, in collaboration with ONR Global, the European Undersea and Barometric Society and the South Pacific Undersea Medicine Society meetings. The physiology symposium series was not continued per se, but the annual program review, held in conjunction with the Deep Submergence Biomedical Development program review, has been a venue to gather the community and assess the overall health of the research. The program has been successful in supporting the graduate education of numerous young investigators who continue to remain in the field. Examples include Aaron Hall and Lt. Geoff Ciarlone at the Naval Medical Research Center, Greg Murphy at the Navy Experimental Diving Unit, and Dawn Kernagis, a recent inductee of the Women Diver’s Hall of Fame. Numerous equipment grants have helped maintain the facilities used to perform this research. Examples include the revitalization of the abandoned program at the State University of New York



Members of SEAL Delivery Vehicle Team Two prepare to launch one of the team’s SEAL Delivery Vehicles (SDV) from the back of a Los Angeles-class attack submarine. The SDVs carry Navy SEALs from a submerged submarine to enemy targets while staying underwater and undetected. Photo by PHC Andrew McKaskle

at Buffalo, the transfer of a Navy-engineered hyperbaric chamber for cellular experiments to the University of South Florida, and the recertification of the chamber at Simon Fraser University. Continued collaborations with ONR Global have supported the international community through the previously mentioned international conferences and funding international research in, for example, Australia, Canada, and New Zealand, and awarding travel to international experts for domestic meetings including the UMed program review.

The UMed basic research investment from ONR remains the sole Department of Defense program dedicated to undersea human performance. The program is well integrated with biomedical efforts in the other services, the Special Operations Command, the Defense Advanced Research Projects Agency, and other institutions such as the National Aeronautics and Space Administration. Strong ties to warfighters and with advanced development partners are cultivated in order to understand the operational challenges and to transition products. The program is producing fundamental biomedical discoveries to both mitigate health risks and augment warfighter capabilities in this extreme environment. The recent global technical awareness study reinforced the findings from 2002 that the NNR was largely responsible for funding international peer-reviewed biomedical literature in UMed. The growing medical field of hyperbaric oxygen therapy is rooted in the Navy's research using oxygen to treat DCS; the growth of this therapy has the added benefit that many hospitals are investing in new hyperbaric chambers. The community also will play a key



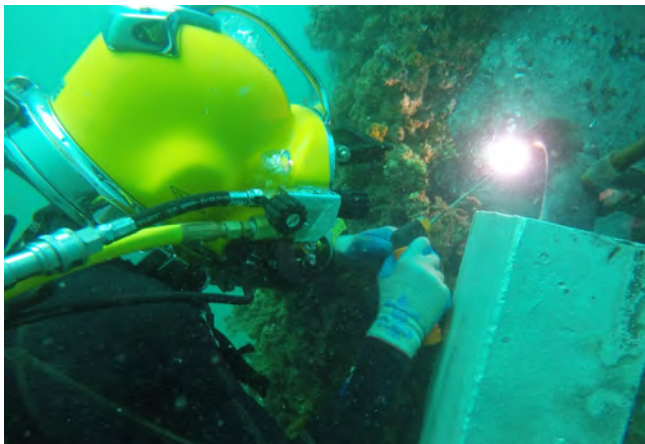
HC2 Beau Chandler, left, prepares a patient for an intravenous line during a demonstration for patient care due to decompression illness in the hyperbaric chamber at U.S. Naval Base Guam. Photo by MC2 Chelsy Alamina

role in the study and mitigation of aviation DCS that has recently arisen with our military aircraft.

The discovery of cellular gas channels under the UMed program is causing the biomedical textbooks to be rewritten. To survive, most cells must take in vital gas such as oxygen and expel waste gas such as carbon dioxide. We were all taught that this is simply done by diffusion of gases from higher concentration to lower through the cell membrane. Walter Boron from Case Western University made the ground-breaking discovery that certain channels can transport gas in a selective manner and he found that membranes can also be impermeable to gas depending on their composition. To bring this research to the next level, in 2016 Boron and his colleagues were awarded an Office of the Secretary of Defense interdisciplinary grant.

Going back to the cell membrane, the UMed NNR has supported another fundamental biomedical finding. It was determined by Stephen Thom of the University of Maryland that the increased pressure faced by tissues during diving causes small parts of the membrane to break off, form small spheres called microparticles (MPs) and enter the blood stream—taking with them whatever proteins were embedded. When these MPs were filtered from an animal showing symptoms of DCS after hyperbaric exposure and injected into an unexposed animal, it also showed DCS symptoms. While it is unknown if all MPs originating from hyperbaric exposure are the same, they have been found to be involved in an immune response and inflammation associated with DCS. Furthermore, it was thought that bubbles in the blood would correspond to DCS. It turns out there is very little correlation—a diver's blood can bubble like champagne without any overt problem. A new theory is that bubbles form around MPs so that measuring MPs could be a better indication of DCS risk. Controlling MP production is therefore an avenue for treating DCS.

Fundamental findings also have been found with respect to hyperbaric oxygen toxicity treatment. Dominic D'Agostino at the University of South Florida evolved a remedy for central nervous system seizures known for several thousand years by the Greeks. It was found that epileptic seizures could be prevented by fasting the patient. In modern times, this finding was updated to prevent seizures using a high-fat, low-carbohydrate diet. Dr. D'Agostino has distilled the theory behind the high-fat diet approach and developed a dietary supplement



CMCS Timothy Plummer, assigned to Underwater Construction Team 2, welds a top portion of cathodic protection to a pile in the port of Sattahip, Thailand. Photo by Builder 2nd Class Benjamin Reed

called ketone esters that has demonstrated the seizure-delaying effect in an animal model. Since these seizures are a storm of activity that sweeps through the brain, it is thought that the ketones are metabolized by the brain through a different pathway thus preventing or delaying the seizures. While the supplement has shown to be non-toxic for short-time use, there is ongoing clinical research to address long-term effects as it transitions to the fleet. The ketone ester supplement also acts like a high-density fuel that may improve the performance of elite athletes; this is being investigated for use by special warfare operators. Ultimately, the mitigation of hyperbaric oxygen toxicity would open up the envelope for rebreather operations allowing longer and deeper dives.

In the future, the UMed NNR has three high-priority goals for the transition of products to the fleet. The first area of focus is biomedical methods to reduce risks of DCS in a submarine escape scenario (which, by corollary, would apply to all Navy diving). This will entail the further study of the role of the immune and inflammatory responses in the mediation of DCS, biochemical methods of decompression, gas solubility manipulations, genetic studies of susceptibility and resilience to DCS, and the determination of biomarkers of decompression stress. The development of methods to eliminate decompression obligation would enable safer, more useful dive profiles, more efficient use of the limited number of divers, and less costly missions. The reduction in the need for recompression chambers and evacuation assets to treat DCS would decrease the logistic burden and cost of undersea operations.

The second area of focus is the prediction and prevention of hyperbaric oxygen toxicity to the central nervous system, pulmonary system, and neuromuscular system. Testing is planned for two parallel approaches to delaying or preventing seizures. Combinations of two anticonvulsant drugs and in parallel combinations of several ketogenic supplements will be tested for efficacy and potential side-effects. While this phase of testing will occur in an animal model, because these substances are either Food and Drug Administration-approved or will be shortly, human testing is on the horizon. This is an important distinction since the path to new drug development is prohibitive for the Defense Department; it would likely take a decade and on the order of half a billion dollars to receive approval with only about a 2-percent chance of success. The products of the UMed NNR do not always translate into hardware; results are often guidance for exposure to hazards or changes to procedures.

The third area of focus is the collection of human performance baseline data for the typical special warfare combat swimming and SEAL delivery vehicle environments. In addition, methods and tools for human performance assessment in these environments will be developed. This is a vital first step in the development and assessment of mitigation strategies for challenges such as thermal stress.

Now 15 years after the original study by the Undersea and Hyperbaric Medical Society, the UMed program continues to meet the criteria of being an area of research that is uniquely important to the Navy, not otherwise adequately funded by non-naval sources, and at risk of loss of a national research capability. The NNR has allowed a stable funding profile, support for the training pipeline, and maintenance of essential infrastructure assets. A series of workshops with the UMed scientific and operational community in 2016 gave an opportunity to recount progress in the field and scope current challenges. UMed will continue to support overcoming human shortcomings from exposure to extreme environments and the expansion of the undersea operational envelope. ✈

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FINDING SOLUTIONS FOR PHYSIOLOGICAL EPISODES IN NAVAL AVIATION

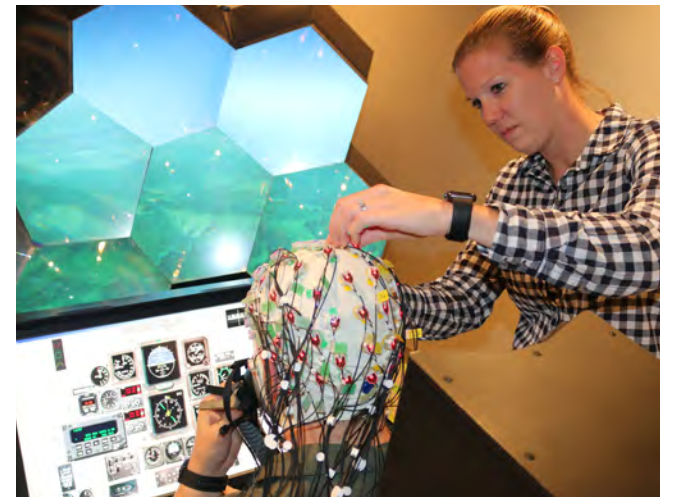
By Lt. Todd R. Seech, MSC, USN; Lt. Adam T. Biggs, MSC, USN; and Dr. Matthew Funke

OVER THE PAST SEVERAL YEARS, THERE HAS BEEN A SHARP RISE IN EVERYTHING FROM DIZZINESS TO INCAPACITATION IN PILOTS OF NAVY AND MARINE CORPS AIRCRAFT. GETTING TO THE BOTTOM OF THESE TROUBLING INCIDENTS HAS PROVEN TO BE A CHALLENGE.

Healthy warfighters are lethal warfighters. Although equipment maintenance and training to operational readiness are important, the capabilities of our fleet begin with the good health of our personnel. Critical health issues range anywhere from our annual physical readiness programs to staving off performance detriments in extreme environments. This latter example serves as a central problem for the aviation community, in which aircrew members must operate in settings that often are at odds with human physiology. As a result, these warfighters can experience a variety of medical issues that directly impact their readiness and can compromise operational performance.

Medical issues that manifest in-flight are generally referred to as physiological episodes (PEs), and can range from vague physical sensations (e.g., dizziness, headache) to complete incapacitation. Needless to say, these impairments—whether minimal or pervasive—markedly increase the operational risk to the affected aircrews. Alarming, we have seen a dramatic rise in frequency of reports in recent years. Although PEs occur in all aviation communities, the Navy's tactical jet community appears to be the most affected. From the Navy's jet trainer, the T-45 Goshawk, to the classic workhorse F/A-18 Hornet, to the new F-35 Lightning II, no aircraft model appears immune to this emerging crisis. This phenomenon has resulted in numerous aircraft and aircrew groundings for maintenance/aeromedical examination as well as temporary suspension of flight for entire airframes, which has stymied the aviation training pipeline and threatens to downgrade our operational readiness. Most concerning of all, however, is that the definitive cause of these PEs has not yet been identified, and remains one of the most pressing aeromedical issues facing military aviation.

To understand how these events affect aircrew members, aeromedical experts are examining reported PE symptom sets across a wide variety of scenarios. Multiple health issues also emerge across different missions as well as different aircraft. Hypoxia, pressure fluctuations, and contaminants in breathing air are among a long list of proposed potential causes of PEs. Regrettably, this aeromedical challenge has been exacerbated by the vague, inconsistent, and idiosyncratic presentations of symptoms, which make prediction and mitigation especially difficult. Here we will discuss several issues in the pursuit of the causal agent of PEs, including: the scope of the problem, the prime medical challenges already known to affect aviation, and several projects the naval aeromedical community has undertaken in response to the health and operational needs of our aircrews.



Dr. Kara Blacker, a research psychologist with the Henry M. Jackson Foundation for the Advancement of Military Medicine, adjusts EEG electrodes and mask fittings on a research participant taking part in a study examining real-time brain changes associated with hypoxia and their effect on operational performance. Photo by Megan Mudersbach

Scope of the Problem

PEs are not a new phenomenon; they have been a recognized risk in aviation since Jacques Charles experienced one of the first PEs in his hot air balloon in 1783. Instead, the current problem involves a sharp increase in reported PEs in recent years. Regarding the T-45, reported PEs occurred at a yearly rate of 11.86 events per 100,000 flight hours during 2012. The rate increased to 16.22 per 100,000 flight hours in 2013, then 18.43 in 2014, and peaked recently with 44.99 and 46.97 in 2015 and 2016, respectively—thereby increasing nearly 300 percent in five years (as reported publicly to the House Armed Services Committee).

In light of this increasing rate, the chief of naval air training recently ordered a stand down of all T-45Cs, which temporarily shut down the aviation training pipeline and constituted one of the largest impacts an aeromedical concern has ever had on naval aviation training. Although a reduction of T-45 training flights provided a temporary solution, a definitive aeromedical cause remains elusive.

Leaders cannot help but compare the current situation to the Air Force's F-22 Raptor PE crisis of 2011, during which the entire F-22 fleet was grounded due to a rapid increase in reported PEs. The current problem facing naval aviation, however, is occurring in more than one aircraft model. All variants of the F/A-18 are exhibiting increased frequencies of PEs, including the EA-18G Growlers. In the aforementioned House report, the PE rate per 100,000 flight hours for F/A-18A-F increased from

Photo by Lance Cpl. Andy Martinez

19.55 in 2010/2011 to 88.29 during the same time frame in 2015/2016. With concerns now mounting regarding the F-35, the pressure to identify the causal aeromedical and engineering issues is higher than ever, with stakes including potential loss of resources, clogged training pipelines, and even fatal mishaps.

The Usual Suspects

Although a few primary points of failure were generally agreed upon during the F-22 PE crisis in 2011 (e.g., poorly fitted upper pressure garment), many experts argued that the actual cause involved a complex interplay between human physiology and aircraft design. As the PE issue now appears to be resurfacing in several new venues, experts warn that we may be facing a multifaceted problem. Many of the same suspected causes from the F-22 issue remain for the current crisis, which include hypoxia (insufficient oxygen to the brain), pressure oscillations, and carbon dioxide imbalances in the body (hypocapnia or hypercapnia). Also worthy of note, some remnants of the F-22 crisis may prove to further confuse investigators trying to identify causes of current PEs, including a fixation on oxygen system contaminants causing PEs despite a lack of corroborating data.

Further compounding an already complex problem is the myriad of less recognized issues that could also contribute to the transient and vague symptoms associated with a



In April 2017, the Navy issued an “operational pause” to all flights by the T-45C Goshawk, the Navy’s primary jet trainer aircraft. Although limited flights at restricted altitude soon resumed, the Navy’s pilot training program was severely affected for several months. Photo by MC3 Nathan T. Beard

PE. Issues such as hyperthermia, dehydration, motion sickness, and fatigue are only a few of the physiological insults that could result in PEs in flight. The combination further complicates any attempt to find a solution because no single source may be responsible for the increase in PEs—and certainly no single source is responsible for all PEs in general. Still, many current initiatives in aircraft design are focused on finding the best sensors and fitting them into the cockpit, which represents even more obstacles in identifying the causal factors behind the increased PEs.

The More Sensors We Come Across, the
More Problems We See

Today, experts are engineering methods to assess the intricate physiological patterns and fluctuations of human operators. Physiologic sensor suites that collect real-time data in pulse-oximetry, heart-rate variability, internal temperature, hydration, and other areas seem to rule the day. The resulting new philosophy appears to involve the assumption that “Big Physio Data” will identify the culprit as well as the mitigation strategy. In other words, we seem to believe that there is a sort of critical mass for physiological data that will unveil the secrets of human performance in flight—that we just need to strap enough sensors onto our aircrews.

This strategy has an inherent flaw: the idiosyncratic nature of human physiology and its transient connection to performance. Each person’s physiological response to hypoxia, rapid pressure change, hypocapnia, and other physical insults is somewhat different than that of other people, which makes predicting subtle performance decrements using physiological data difficult. A possible solution to this problem would be to move the focus of assessments from traditional physiological sensors to more direct measures of brain functioning, which may have a more direct connection to performance, as physiological inputs must filter through the brain before behavioral performance is produced.

At Naval Medical Research Unit-Dayton, multiple ongoing research projects are under way focusing on assessing real-time neurological data through noninvasive and nondistracting sensors. A prime example is a study currently funded by the Office of Naval Research’s basic biomedical portfolio, which examines how an electroencephalograph, or EEG, signal known as Mismatch Negativity can give real-time information

about an operator’s ability to perform given his/her neurological state. While this research is encouraging, the immature status of the technology (e.g., sensitivity to electromagnetic noise) means that it is unlikely to be ready to solve today’s PE issue. Even so, assessing operator performance by focusing on a more universal predictor of performance deficits, such as brain functioning, may have the propensity to prevent the PE crises of tomorrow by providing a more universal and consistent measurement scheme.

To achieve this end, military medicine must continue to support basic biomedical research and solutions, even if they may not solve the most immediate crises. Taking this broader view of PEs will allow scientists to stay ahead of the next aeromedical challenge by investing in a future technology that can keep our aircrews informed about their neurological state—no matter what the physiological cause—and ultimately keep our aviators healthy, ready, and ahead of their aircraft.

A New Approach

These aeromedical problems will persist as long as there are human operators placed at extreme altitudes and within dynamic envelopes. The research challenge is to reduce these physiological and cognitive impairments as much as possible, in light of the dramatic increase in recent PE rates. To that end, the recent episodes provide insights regarding how we should move forward.

It is unlikely there will be a “smoking gun” that explains the variety of aeromedical issues being observed. As long as there are humans in the cockpit, operators will be subject to any number of physiological and cognitive impairments that have interactive and multiplicative relations with one another. Perhaps there might be, however, a “silver bullet” solution to detecting PEs prior to performance decrements that involves shifting the primary focus from physiological evidence to neurological evidence, which might help to limit potential sources of error. Physiological symptoms are inherently complicated to address because they generally do not correlate with actual changes in performance. Based on the inherent variability in physiology and behavior from individual to individual, this solution would have to involve measurement at the “bottleneck” between physiological inputs (e.g., pulse oximetry, respiration, temperature) and performance outputs (e.g., aircraft control). This approach then takes a step toward identifying the actual problem rather than merely recognizing that a



It is unlikely there will be a single cause that explains the recent rise in aeromedical physiological episodes. There may be a better way of detecting these episodes prior to their occurrence that involves shifting the primary focus from physiological evidence to neurological evidence. Photo by MC3 Wyatt L. Anthony

problem exists. Further, while data collection in flight using technologies such as EEGs requires notable miniaturization and hardening before being field-ready, this direction presents a viable way forward in detecting the PEs of the future, no matter the causes.

The persistence of PEs across aircraft types also demonstrates the importance of medical research to naval aviation. Human operators are the one commonality across aviation platforms, which makes aeromedical problems ubiquitous in aviation. In addition, when these issues become too severe, they can, and have, resulted in the grounding of entire aircraft types in the fleet—a prospect that deals a critical blow to our national security. Medical research in this sense thus matters most outside of the hospital rather than within one. Resolving these aeromedical issues, or staying ahead of them, is fundamental to the operational readiness of our fleet. ✈

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MODERN TOOLS FOR MODERN MEDICAL PLANNING

By Michael Galarneau

PLANNING FOR MASS CASUALTY EVENTS IS A CHALLENGE IN BOTH WARTIME AND PEACETIME. GETTING RESOURCES IN PLACE AND KNOWING WHERE PEOPLE NEED TO GO CAN MEAN THE DIFFERENCE BETWEEN LIFE AND DEATH.

The concept of medical planning is not new. Throughout the Civil War, Clara Barton collected and delivered wagon loads of bandages and other medical supplies to U.S. Army doctors caring for wounded Union soldiers. Barton, a trailblazer in combat care, also tended to the wounded on battlefields and prepared them for evacuation.

By World War II, most medical planning was done using field manuals, which depended on “rules of thumb” and lookup tables to predict casualties. This process was an improvement on earlier methods and relied on mathematical formulae to predict casualty counts based

on the population at risk, offensive/defensive posture, and a planner’s estimate of an appropriate casualty rate based on the anticipated operation.

There were many problems with planning this way. Results were inconsistent and couldn’t always be replicated, which meant that two separate planners could (and frequently did) obtain widely different estimates on the number of casualties. In addition, this methodology wasn’t transparent—it hindered planners’ ability to communicate with others about how they arrived at their estimates, and the lack of documentation prevented consistent reconstruction of the estimation process.

Aside from these drawbacks, there was one other problem: this method of medical planning only took into account the estimated number of casualties and didn’t include an estimate of the resources that would be required to care for those casualties. Until recently, this was how medical planners prepared for war.

Modernizing Methods for Medical Planning

As military warfare has evolved, often at a rapid pace, the need to more accurately determine what medical resources and personnel are needed has become critical. The right medical care at the right time and place is the difference between life and death.

Fortunately for modern warfighters, today’s military medical planners don’t have to rely on techniques from World War II. Data scientists at the Naval Health Research Center (NHRC) have developed a set of computer-based tools, using science and empirical data, to help planners maximize survivability and health outcomes for combat-injured service members.

The Medical Planner’s Toolkit (MPTk) and the Joint Medical Planning Tool (JMPT) provide repeatable, documented, empirical, science-based methods to predict the likelihood of injuries and illnesses; create casualty estimates; simulate routing and treatment times; estimate required equipment, supplies, personnel, and transportation assets; conduct medical systems analysis; and assess operational risk.

The MPTk not only provides daily estimates of the number of casualties across the range of military operations, but also the types of injuries and illnesses that can be expected based on the mission. Knowing whether to anticipate blast injuries, chemical burns, or vector-borne illness enables medical personnel to provide the right level of care and treatment, ensuring the best health outcomes for afflicted service members. It also allows medical planners to calculate the number of operating rooms, intensive care unit beds, medical/surgical ward beds, blood products, surgeons,

nurses, hospital corpsmen, and other medical supplies and resources necessary to provide optimal patient care and effectively manage the medical workload.

The JMPT combines all the information about casualty streams and resources from the MPTk to examine the trade-offs in distance between military treatment facilities, the types and roles of these facilities, the number and specialties of medical personnel, and the availability of transportation assets. This ensures that medical planners can determine the best course of action in an evolving warfighting environment to meet the needs of wounded and ill service members, giving them their best chance of survival while optimizing their long-term health outcomes.

The Power of Data

So how do these tools work? How have NHRC’s researchers been able to achieve what medical planners throughout history have struggled to achieve? It’s all about harnessing the power of data.

The term “big data” may be new, but the concept is not. For more than 37 years, researchers at NHRC have been doing a lot with data. Before there was JMPT and MPTk, there was the Expeditionary Medical Encounter Database (EMED).

NHRC researchers developed EMED to improve medical mission readiness by providing researchers and medical planners with accurate injury and clinical treatment data for casualties from point of injury to definitive care



A medical vehicle attached to the 24th Marine Expeditionary Unit drives aboard the amphibious assault ship USS *Iwo Jima* (LHD 7) during an onload of more than 500 Marines and nearly 300 pallets of supplies. Photo by PO3 Jess E. Toner



A hospital corpsman with Alpha Battery, 1st Battalion, 12th Marines, demonstrates how to properly apply a tourniquet during a casualty evacuation drill in the Hijudai Maneuver Area, Japan. Photo by Lance Cpl. Christian J. Robertson

and rehabilitation. As Navy and Department of Defense requirements evolved, EMED evolved as a high-quality database to support research on several topics, including: injury prevention and mitigation, personal protective equipment evaluation, quality of life outcomes, clinical practice guidelines, and determination of theater medical requirements.

EMED serves as the “data foundation” for JMPT and MPTk. The capability set comprised in these tools was initiated in the mid-1990s, but have steadily evolved to meet changing conditions and new operational constructs. The only constant in their development is that in order to make their calculations, both continue to depend on the high quality data in EMED, which itself is continually updated. MPTk is actually a suite of separate tools (see sidebar).

Medical planners can use MPTk to estimate casualties across a range of military operations, from combat to humanitarian missions, to help determine what supplies, equipment, and personnel are needed to manage casualties and ensure lifesaving medical care is available.

The JMPT supports mission planners by modeling patient flow from point of injury in far-forward environments through to more definitive care. Fully integrated with MPTk, JMPT allows medical planners to:

- Project patient numbers
- Project types of injuries/illnesses
- Simulate patient routing and treatment times

- Determine type of military treatment facilities required to treat patient streams
- Determine how military treatment facility relocation will impact patient treatment
- Determine best use of medical personnel and transportation assets
- Manage patient flow for optimal health outcomes.

The JMPT is used to support a variety of uses from research and medical systems analysis to operational risk assessment and field medical services planning. Together, the JMPT and MPTk are powerful data analytics tools that provide military leaders and medical planners with reliable, science-based information to support medical decision making to minimize injury and illness and save the lives of warfighters.

Making History with Science

For the first time in the history of military medical planning, the tools developed by NHRC have provided a standardized, repeatable process to support medical planning up to and including the combatant command level, allowing mission planners to calculate and quantify risk. Both tools use stochastic, Monte-Carlo techniques (multiple scenario runs), which permit evaluation of possible variance from the average casualty values and thereby provide measurement and quantification of risk associated with alternative courses of action. Both



A scout observer and a hospital corpsman with 1st Battalion, 12th Marines, prepare a simulated casualty for evacuation at the Pohakuloa Training Area, Hawaii. Photo by Lance Cpl. Khalil Ross

MPTk and JMPT have undergone rigorous verification, validation, and accreditation, and are certified for use across the Department of Defense.

Going forward, researchers at NHRC will continue to upgrade these tools and create new ones to keep up with the rapid evolution of data science and the medical readiness needs of the US armed forces. In the near term, NHRC plans to enhance ability of JMPT and MPTk to calculate casualties caused by chemical, biological, radiation, and nuclear weapon use. The tools also will accommodate calculations of supply and treatment requirements associated with the special needs of these types of patient streams.

To meet the needs of end users, NHRC also is developing web-enabled versions of the tools that will allow faster run times in a distributed environment and can be implemented through cloud computing. Since its earliest days, NHRC has worked to continuously gather, codify, and organize expeditionary medical data in support of the design, development, and deployment of high-quality software based on those data. ✈

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THE MEDICAL PLANNER’S TOOLKIT

The Medical Planner’s Toolkit (MPTk) is a suite of tools that seamlessly integrates four applications into one computer-based workflow. This desktop program provides medical planners with an end-to-end solution for medical support planning across the range of military operations, from combat operations to humanitarian assistance. MPTk consists of the Patient Condition Occurrence Frequency tool, the Casualty Rate Estimation tool, the Expeditionary Medicine Requirements Estimator, and the Estimating Supplies program.

The Patient Condition Occurrence Frequency tool is an application that manages discrete probability distributions. These distributions characterize the probabilities of individual illnesses and injuries. Empirical data show that the number and types of injuries are related to the type of operations that are captured in the data. Accordingly, the tool provides 33 baseline distributions taken from a variety of operational scenarios that span the spectrum from combat missions to disaster relief and humanitarian assistance. Each scenario can be adjusted by users to better fit their planned operations and manage results, all of which can be stored, edited, exported, and imported.

The Casualty Rate Estimation tool provides the capability to emulate a ground operational plan using a 180-day palette to calculate expected battle and noncombat injuries and illnesses during operations. Casualty estimates also can be generated for attacks on ships and

fixed facilities, or natural disasters. This tool uses the Patient Condition Occurrence Frequency probability distributions to turn casualty streams into patient streams, providing not only the number of anticipated casualties, but also the number and types of individual patients. This allows a more refined estimate of the medical requirements for a given operation. For example, it would determine the number and type of surgical patients in a casualty stream, enabling a medical planner to determine the number and type of surgeons that would be necessary, ultimately increasing the number of warfighter lives saved.

The Expeditionary Medicine Requirements Estimator absorbs the time-phased patient stream from the Casualty Rate Estimation tool and calculates the number of operating tables, intensive care unit beds, ward beds, and blood products necessary to satisfy the demand of the patient load. The estimator factors in the medical planner’s inputs on evacuation delay, evacuation policy, and the availability of critical care teams into the requirements estimation.

The Estimating Supplies program uses the scenario-specific patient stream created by the Casualty Rate Estimation Tool and service-specific inventories of medical supplies to estimate the consumption of medically related supplies necessary to treat the patient stream. The supply estimate is time-based, which permits users to estimate the logistics requirements by time period.

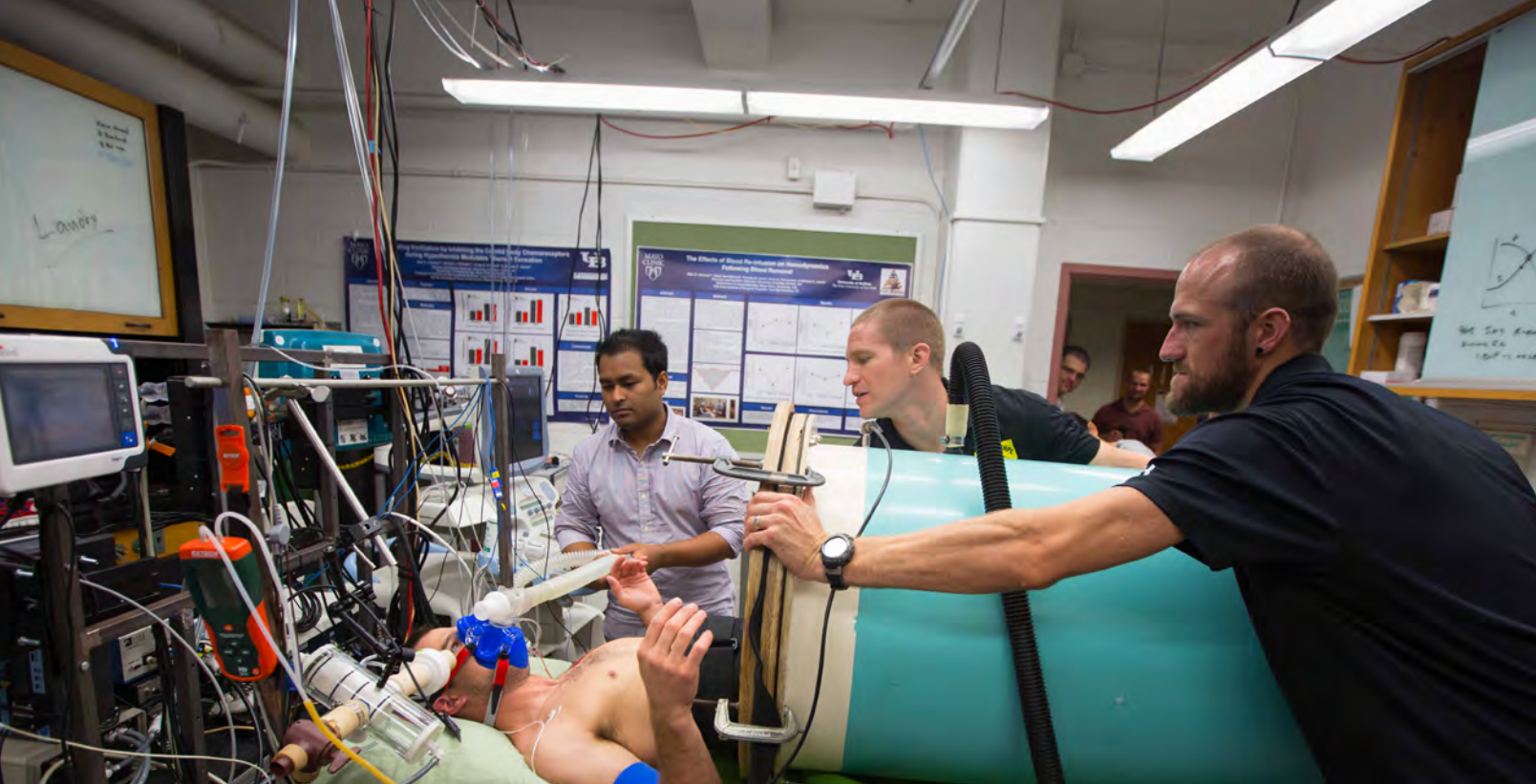


Photo by Douglas Levere

RESEARCH IN SPECIAL ENVIRONMENTS AT THE UNIVERSITY AT BUFFALO

By Dr. David Hostler and Dr. David R. Pendergast

THE CENTER FOR RESEARCH AND EDUCATION IN SPECIAL ENVIRONMENTS AND ITS FACILITIES AT THE UNIVERSITY AT BUFFALO HAVE BEEN AT THE FOREFRONT OF MEDICAL RESEARCH FOR THOSE WHO WORK BOTH ABOVE AND BELOW THE SEA.

Although the Center for Research and Education in Special Environments (CRESE) at the State University of New York (SUNY) at Buffalo was formally established as an organized research center in 1990, its lineage dates back to the 19th century and its collaboration with the Office of Naval Research (ONR) dates to the 1960s.

The medical school in Buffalo was established in 1846. It was believed at the time that a better medical system was needed to meet the demands of a city growing in prominence. The Department of Physiology, the original home of CRESE, was established with the medical school and has operated continuously ever since. At that time, Buffalo was emerging as one of the most important commercial cities in the United States, transshipping

goods from the Midwest to the East Coast and providing a waypoint for settlers from the east to the west. Over the next century, the medical school was joined by additional schools and departments to become a comprehensive private university, which later joined the SUNY system.

The development of the school as a full-fledged academic center led to the recruitment of Dr. Herman Rahn as chair of physiology in 1956. Rahn was joined by Dr. Leon Farhi and retired Capt. Edward Lanphier to reset the research program of the department toward environmental physiology and a future collaboration with ONR. This trio responded to a national request for proposals to create “super laboratories” of excellence. The University at Buffalo submitted a proposal to establish a laboratory with a focus on thermal stress, exercise,

altered gravity, and hyper/hypobaric environments in 1966. The laboratory was supported by the Department of Defense (DoD) and ONR as the National Laboratory of Environmental Physiology. The award was termed the “Themis Project.” The center was nearly abandoned before it began, however, when the university’s partnership with the Defense Department attracted the attention of anti-Vietnam War protests. The faculty senate voted in support of the student protesters to have the president of the university refuse the funding for Themis, so the project was delayed for another two years.

Ultimately, the University at Buffalo erected a building and the DoD and ONR financed the purchase of major equipment including a human centrifuge and hyper/hypobaric chambers. In 1972, a running track, high-pressure chamber, exercise laboratory, and biochemical laboratories were installed to complete the facility. Lanphier would later move the original hyperbaric chamber to the University of Wisconsin at Madison to establish an ONR-supported program performing hyperbaric work in goat and sheep models of decompression illness. That laboratory is still operating today under the direction of Drs. Marlowe Eldridge and Aleksey Sobakin.

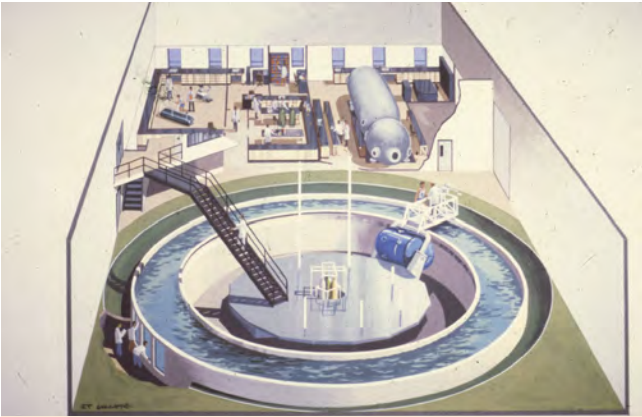
CRESE flourished thanks to the original ONR funding. The infrastructure in the lab allowed investigators to further support the Navy by performing studies that were supported by Naval Sea Systems Command to solve practical issues as well as concentrate on more basic and applied science projects for ONR. The human centrifuge allowed the investigators to perform preliminary work simulating changes in gravity, which resulted in the Space Shuttle Scientific Project (#066 on STS 40 and 41) supported by the National Aviation and Space Administration.

Since its establishment, CRESE has been self-sustaining and productive. Replacement costs are estimated to exceed \$40 million. It is unlikely that a similar center will ever be built again, making it critical to the National Naval Responsibility Initiative in undersea medicine. The initial funding and continued ONR support in maintaining the CRESE facilities has allowed the center to leverage its position and obtain funding from additional sources to support its personnel and infrastructure. This resulted in up to \$1 million from industry, \$2 million from other federal institutions, and more than \$7 million from other branches of the military in the early 2000s. It is not an overstatement to say that without ONR support the laboratory would not exist today. This support is particularly important in the current era as environmental laboratories are disappearing around the world.

In 2008, ONR awarded CRESE a Defense University Research Instrument Program award, which allowed the complete refurbishment of the hyper/hypobaric chamber and purchase of modern measurement instrumentation. ONR also contributed funds to conduct an international symposium in Buffalo focusing on critical issues in undersea medicine. The proceedings from that symposium were published in a special issue of the Journal of Applied Physiology.

Another important aspect of ONR funding is the support for training future generations of scientists in environmental physiology and hyperbaric medicine. Over the years, ONR has routinely supported postdoctoral fellows who trained in CRESE. Several CRESE alumni assumed leadership positions in universities and in the Navy. Notable examples are Capt. James Vorosmarti, Capt. Edward Flynn, and Capt. Edward Thallman, who were all leaders in undersea medicine. In addition, CRESE has trained more than 100 undergraduate students, 98 graduate students, 20 medical students, 30 summer fellows, 32 postdoctoral fellows, and 24 distinguished visiting scientists from 15 different nations.

In spite of its success, CRESE met the fate of many other environmental physiology labs in 2013 when it was closed by the School of Medicine in anticipation of moving to a new downtown campus. Fortunately, this coincided with the arrival of the Emergency Responder Human Performance Lab (ERHPL) in the Department of Exercise and Nutrition Sciences. ERHPL had a similar environmental physiology focus for first responders and was able to acquire a portion of the CRESE infrastructure. Two years later, with the support of the Deans of Medicine, and the School of Public Health and Health



Artistic representation of the original laboratory funded by the Department of Defense and ONR as part of the Themis Project in the early 1970s. The main element of the laboratory was the hyper/hypobaric chamber funded by ONR. The chamber has a working pressure of 5,600 feet sea water and an altitude of 100,000 feet.

Professions, CRESE reopened and ERHPL became one of three labs operating within the center.

However, after two years of sitting idle, much of the equipment, including the hyperbaric chamber, was in poor repair. Once again, ONR was instrumental in CRESE's success. A Defense University Research Instrument Program grant was awarded, which allowed the university to rehabilitate the hyper/hypobaric chamber and to purchase equipment for data collection. Further research support was provided by ONR and Dr. William D'Angelo. Once again, this early support from ONR allowed CRESE to apply for grants from Naval Sea Systems Command and operate a fully functioning research and training program. Currently, CRESE is led by Dr. David Hostler (also director of ERHPL) and supports two additional researchers; Dr. Blair Johnson (director of the Human Integrative Physiology Lab) and Dr. Zachary Schlader (director of the Thermal Physiology Lab). All three are supported by ONR or Naval Sea Systems Command and contributing to the National Naval Responsibility Initiative.

Important Projects

CRESE was built on a legacy that began at the University of Rochester. Fenn, Rahn, and Ottis were recruited by the military to perform basic science studies to address military-relevant questions during World War II. Their work determined the supplemental O2 requirements to fly at higher altitudes in unpressurized aircraft and the hydration requirements for soldiers fighting in the African deserts. Rahn's move to the University at Buffalo and the refocusing of the department on environmental issues in humans and animals led to the development of the laboratory, which was later named for him and eventually officially recognized as CRESE.

There were two initial areas of interest after establishing the environmental focus of the laboratory. The first was studies focused on breath-hold diving, including alveolar gas exchange and end-tidal gas measurement. The second was field studies describing the diving pattern, breath-holding capacity, and thermal stress of Ama divers (Japanese pearl divers). These studies set the stage for laboratory studies in the hyperbaric chamber, including simulated breath-hold diving to 50 meters to describe the cardiovascular changes, alveolar gas composition, CO2 storage capacity, and ventilatory responses to hypercapnia (elevated CO2 levels) and hypoxia in elite breath-hold divers.



The hyper/hypobaric chamber and associated measurement equipment.

Another early focus was on deep sea diving. In the 1960s, prior to remotely operated vehicles, deep diving was of critical interest to both commercial and military communities. Studies were conducted on mice and humans examining pulmonary gas exchange when ventilated with oxygenated liquid. Other ONR-supported studies allowed the design and construction of "mini hyperbaric chambers" that allowed measurements on single living cells at elevated pressure.

In recent years, CRESE studies have focused on the mechanics of breathing, work of breathing, and ventilation-perfusion relationships using both theoretical and experimental methods. We have examined the effects of gas density during submersion and the effect of depth, static lung load, and posture on the heart and lungs at depth. Work performed at CRESE on the dead space in breathing apparatus contributed to the acceptable breathing resistance standards in working divers. The effects of the increased work of breathing and carbon dioxide retention have been a major focus of the laboratory.

Recently, ONR-supported studies that have quantified the effect of both submersion and depth on the work of breathing as well as the energy cost of breathing. These studies showed that improving respiratory muscle strength and endurance by respiratory muscle training reduces the work of breathing and the energy cost of respiration at depth. Those improvements in respiratory function increased exercise endurance on land and at depth making warfighters more effective.

The unique infrastructure allowed CRESE investigators to develop animal and human models to challenge the long-standing "Gauer-Henry" hypothesis of the link between the cardiovascular and renal systems. These studies collectively established the concept of autoinfusion of fluid from the cells to the intravascular compartment during immersion,

which increases plasma volume. This, combined with hydrostatic pressure, results in translocation of fluid to the chest, increased stroke volume, and greater cardiac output. The presence of both expanded plasma volume and hormonal changes results in the immersion diuresis and eventually a reduction in plasma volume. These studies led to the questioning of rehydration during immersion and one of the current studies being performed in CRESE.

CRESE also is known for its ONR-supported work on diver thermal protection. Theoretical models and experimental data have documented the heat transfer in water of different temperatures at rest and during exercise. More recently, we have shown the effect of body cooling on oxygen transport during exercise, including reductions in cardiac output and skeletal muscle blood flow. The reduction in subcutaneous and muscle blood flow act as insulation during cold water diving. With the recognition of unsolved cold stress issues and the emergence of warm water issues, a second international symposium was held at CRESE to examine new technologies and strategies for thermal protection. ONR supported CRESE to develop a diver thermal protection system for use in both cold and warm water. A system was developed that could protect divers in water at 5 to 40 degrees Celsius down to a depth of 300 feet sea water, and served as a regional and total body calorimeter providing data for the power requirements to maintain diver thermal comfort. This system was transferred to NEDU for further exploration.

Current Projects

CRESE continues to advance the basic and applied science of diving. A current ONR-supported project entitled "The role of oxygen breathing on carotid body sensitivity, oxygen toxicity, and performance in divers" is ongoing. The research will determine if carotid body chemosensitivity is altered during and following a dive and if breathing 100-percent oxygen during a dive alters carotid body chemosensitivity when compared to breathing 21-percent oxygen.

Dr. Blair Johnson was awarded the ONR Director of Research Early Career Grant for his project entitled "Autonomic Activity and Water Immersion." This study will investigate the changes in direct recordings of sympathetic nerve activity during various conditions associated with diving (thermoneutral water, cold water, breathing hyperoxia, breathing hypercapnia). These studies will provide important insights regarding the control of ventilation and circulation during water immersion.

Naval Sea Systems Command continues to use CRESE resources to enhance diver safety and performance and is currently funding three projects. The first is entitled "Optimizing performance during topside operations at altitude." There is little information available on the decompression stress of divers working at altitude. This proposal will examine the effects of respiratory muscle training on performance during topside operations and during diving at altitude. It also will explore the decompression strain that occurs after diving at altitude by assessing venous gas bubbling after diving at 12,000 feet of altitude.

Additional ongoing projects include examining rehydration strategies for Navy divers and special warfare operators exposed to prolonged immersion, who then proceed to land exercises, and the physiologic strain associated with prolonged exposure in a disabled submarine using a pressurized rescue module (PRM). Safe deployment of the PRM is dependent on understanding and mitigating the possible challenges if failures were to occur. If the PRM were to become disabled, the environmental conditions could quickly challenge the health and safety of those inside. There are no models capable of accurately predicting these variables in a hyperbaric, humid, and warm environment. This study will determine the magnitude of increases in core body temperature or reductions in body fluids incurred in a warm and humid disabled PRM scenario at sea level and at depth.

Historically, CRESE's research has focused on the performance and safety of Navy personnel. Now positioned in the Department of Exercise and Nutrition Sciences, CRESE has additional expertise to renew that focus to explore and improve human performance in extreme environments—including new physical training paradigms, nutrition, thermal protection, and decompression strain with the aim of addressing field conditions using scientific techniques and methods.

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Photo by Bre Zinter

THE NAVY'S OLDEST CERTIFIED DIVE CHAMBER STILL HEALS UNDER PRESSURE

By J. Overton

FOR MORE THAN 80 YEARS, THE NAVY'S HYPERBARIC CHAMBER AT KEYPORT, WASHINGTON, HAS HELPED SAILORS, BOTH YOUNG AND OLD, TO TRAIN FOR THE MYSTERIES OF THE DEEP—AND TO HEAL FROM SICKNESS.

The Navy's oldest certified dive hyperbaric chamber, at Naval Undersea Warfare Center Keyport Division (NUWC Keyport) in Washington, was designed and built for one vital and unique function: treating divers who suffer from decompression sickness, the dreaded "bends." Its capabilities have expanded over the years, and it now also provides specialized medical treatments for far more than diver-related problems.

NUWC Keyport has had Navy divers since at least 1920. At that time, NUWC Keyport's primary mission was to test torpedoes for speed and accuracy before they were issued to the Pacific Fleet. Part of that mission was training torpedomen from the fleet to repair and operate torpedoes. While at torpedo school, these Sailors also could qualify as Navy divers and be able to retrieve torpedoes that, during in-water testing, had failed to surface. If those early Keyport divers suffered the bends, they had to make the long transit to Victoria, British Columbia, to use a recompression chamber on a cable-laying ship, or, more commonly, were simply resuited in their dive equipment and sent back to depth for a more gradual ascent.

NUWC Keyport (then called the Naval Torpedo Station-Keyport) received its hyperbaric chamber, built and certified in 1930, sometime in the 1930s or 40s. It was used for countless decompression treatments for Keyport personnel and other divers over the following decades.

In the 1970s, doctors discovered that breathing pressurized oxygen could speed the healing of wounds that, because of complications such as diabetes or injuries from radiation treatments, wouldn't otherwise heal. The lungs gather more oxygen than would be possible breathing pure oxygen at normal air pressure, and blood carries this oxygen throughout the body to fight bacteria and stimulate the release of growth factors and stem cells. As of 2017, hyperbaric oxygen therapy has been accepted by the Food and Drug Administration as an indicated treatment for approximately 14 medical conditions, including some persistent infections, poorly healing skin grafts, and carbon monoxide poisoning.

NUWC Keyport began using its chamber, known as the "Whale," for these treatments in the early 1990s. Since then, it has helped the recovery of dozens of veterans and other eligible beneficiaries.

One case was that of a civilian employee of NUWC Keyport, Richard Larvia. He was diagnosed with throat cancer, and though months of radiation and chemotherapy helped stopped the cancer's spread, it also caused an

opening on the inside of his mouth that would not heal under normal conditions. His doctor's prescription to repair this tissue damage involved weeks of daily treatments in a pressurized, oxygen-rich environment. If taken at the nearest commercial facility, in Seattle (more than an hour from NUWC Keyport's headquarters), these treatments would have involved additional weeks away from work. Knowing that Keyport had a compression chamber in their diving locker, Larvia asked if treatment would be possible there. After discussion with the diving locker staff, and receiving permission from the Navy's Bureau of Medicine and Surgery, Larvia was able to undergo the treatments at Keyport with minimal time away from his duties.

Five times a week, for six consecutive weeks, Larvia would spend an hour and a half inside the chamber, going through a compression and decompression evolution to help oxygen more quickly reach and heal his damaged cells. Larvia would be in the chamber with a medically-trained diver, while several other divers operated the chamber from outside. "They made me very comfortable," he said. "They really took care of me." Larvia's cancer has now been in remission long enough for him to be considered cancer-free.

The treatment sessions also helped the readiness of NUWC Keyport's dive locker: the chamber, usually available to treat decompression sickness, must be kept in working order at all times, and divers need to find meaningful ways to maintain their qualifications in its use. Larvia's daily sessions provided just such an opportunity.



CWO4 Ray Miller administers the reenlistment oath to ND2 Buck Barr at a simulated depth of 165 feet of seawater inside of NUWC Keyport's hyperbaric chamber. Navy divers have a tradition of reenlisted under pressure, either in an actual open-water dive or in a chamber. The particular depths of 165 and 135 were chosen because 165 feet is the deepest Keyport divers are certified to dive, but prior to those maximum-depth dives, they may do a shallower work up dive down to 135 feet. Photo by Bre Zinter

►► THE NAVY'S OLDEST CERTIFIED DIVE CHAMBER
STILL HEALS UNDER PRESSURE

Similar treatments were performed recently in the chamber by Cmdr. Juan Dapena, Submarine Group 9's undersea medical officer and NUWC Keyport's dive locker, to treat retired HMCS Roger Johnson, who went through radiation treatment for oral cavity cancer that affected his jaw area.

Dapena noted that because of his radiation treatment for oral cancer, Johnson was at risk of developing a condition known as osteoradionecrosis in his jaw. Before any needed oral surgery is performed, especially the removal of teeth, hyperbaric oxygen therapy, provided prior to surgery, can be designated to reduce radiation-related complications and enhance surgical site healing.

According to Dapena, the air pressure in the dive chamber is increased higher than normal, thereby simulating being underwater, with Johnson breathing 100-percent oxygen through a mask. The hyperbaric chamber is manually pressurized under controlled conditions by the Navy

dive team to an equivalent depth of 45 feet of sea water pressure with 100-percent oxygen affecting all body tissue, which Johnson received for his three 30-minute sessions. The five minute breaks between the sessions are to prevent side effects such as seizures.

In October 2017, retired Lt. Cmdr. David Maxwell began "Whale" treatment for post-jaw surgery injuries. His treatments were coordinated and supervised as would an actual dive in open water, with similar preparations and safety checks. While the chamber's insides may seem cramped and spartan to some, Maxwell had no complaints. "There was a padded bench to sit on," he said. "For someone who's spent years at sea, that's plenty comfortable."

NDCM David Glidewell, NUWC Keyport's master diver, said that the chamber performs about 60 treatments a year, averaging 30 treatments per patient.



Under the watchful eye of ND2 Joseph Ziemba, inside tender responsible for safety, retired HMCS Robert Johnson receives hyperbaric oxygen therapy to help prevent complications from radiation treatment in the Navy's oldest certified dive chamber. The air pressure in the chamber is increased higher than normal, thus simulating being underwater, with Johnson receiving 100-percent oxygen through the mask instead of the normal 21-percent oxygen range at sea level. Photo by Douglas H Stutz



It's also, of course, still ready when needed for its original purpose—although with the addition of technology, like helicopters, that was not available in 1930.

In July 2017, NUWC Keyport's dive locker teamed up with Mobile Diving and Salvage Unit 1, from Honolulu, Hawaii, to conduct a dive-related injury recompression chamber drill. The drill began at Naval Air Station Whidbey Island with a simulated victim suffering from the bends being medically evacuated by helicopter to NUWC Keyport to use the chamber. The simulated victim was dropped off at NUWC Keyport, evaluated by local emergency medical technicians, and then loaded into an ambulance to be transported to NUWC Keyport's dive locker to be treated in the recompression chamber.

"Innovation isn't just about creating new equipment or technology," said Anna Long, NUWC Keyport's organizational planner. "It's also about improving and expanding the uses and capabilities of existing technology, and that's definitely an integral part of Keyport's culture.

The ways we use the hyperbaric chamber are a great example of that. We're taking equipment that's basically been unchanged for a century and using it to solve problems that the original designers never imagined it could."

With the Whale now nearing its 90th year of operation and still in excellent condition, only time will tell what other uses and solutions the innovative and capable people of NUWC Keyport will find for it in the next century. ✈

About the author:

J. Overton is the writer/editor for Naval Undersea Warfare Center Keyport. He wishes to acknowledge the additional help of Doug Stutz with Naval Hospital Bremerton and PO2 Wyatt Anthony of Navy Public Affairs Support Element, Det. Northwest.

THE KRAKEN GOES TO BATTLE AGAINST SPATIAL DISORIENTATION

By Capt. Rich Folga, USN

WITH MULTIAxis MOTION CONTROL TO INVESTIGATE SPATIAL DISORIENTATION COUNTERMEASURES, NAVAL MEDICAL RESEARCH UNIT-DAYTON HOUSES THE DISORIENTATION RESEARCH DEVICE—ALSO KNOWN AS THE KRAKEN.

The Disorientation Research Device (DRD), otherwise known by its official Navy-branded moniker, the Kraken™, is the Navy's newest weapon in the battle against a long-standing noncombat threat to aviators and aircrews: spatial disorientation (SD). The DRD was created to provide unprecedented research capability to address this persistent threat. By replicating acceleration forces experienced in flight and integrating high-fidelity flight or other vehicular displays, the DRD can produce dynamic conditions under sustained G forces (up to 3G) with man-in-the-loop control of motion with authentic sensory stimulation. During these conditions, researchers can measure actual sensory spatial reflexes and monitor subject physiologic parameters. Other research applications for the DRD include study of all forms of motion sickness, human systems integration validation of helmet mounted displays, specify areas of neural activation during dynamic motion, developmental life support equipment test and evaluation, recreation

of aircraft mishaps and dynamic effects of hypoxia on performance.

As the program manager for the Kraken, I am charged with developing this unique capability into an SD research and countermeasure test bed, targeting the most persistent aeromedical cause of fatal aircraft mishaps, one that strikes across platforms and services. The Kraken is housed and operated in the Naval Aerospace Medical Research Lab (NAMRL) at Naval Medical Research Unit-Dayton.

After accepting the \$19-million device from the contractor in October 2016, our team of engineers, mathematicians, and technicians is pulling together to complete a long list of crucial tasks for development of this long-awaited, one-of-a-kind multiaxis acceleration research platform. No other research capability like the Kraken exists in the United States.

While primarily designed as a basic research tool, the Kraken was given a special feature called external motion control (EMC) mode, which allows for some advanced applied research exploration. We are very focused on developing the EMC mode, our man-in-the-loop mode where subjects can control the device from inside the capsule. This is of utmost interest for our team and the SD research program when it comes to the study of actual in-flight aviation SD. The device requires significant development effort because of the complexity of multi-axis motion control. The vehicle model must mesh without significant artifacts affecting subject perception. Working toward this goal, my team continues to demonstrate several advancements in algorithm development, system architecture, and communication with the Kraken's nerve center using the EMC mode.

Since completing staff maintenance and operator training in December 2016, the DRD team has switched to preoperational readiness and research preparation. To get the Kraken to initial operational capability, we will refine the organic maintenance program, complete an internal command safety assessment, man-rate the device, continue developing all axis motion washout algorithms, upgrade facilities, and work through various flight model integration and validation steps.

One of our key priorities is the maturation and preservation of the multidisciplinary core DRD team who function as the operators, developers, and maintainers. The current transition from Kraken caretakers to research device operators requires refinement of the operational model and training for specific device positions.



The Kraken team is working through various flight model integration and validation steps at Naval Medical Research Unit-Dayton. Photo by Megan Mundersbach

As a supplement to a small initial cadre of maintenance and engineering staff appointed to tame the Kraken, we have enlisted the help of the Office of Naval Research reserve engineering support program. This select group of seasoned naval aviators with engineering backgrounds provides valuable support in the areas of preoperational program development, preplanned product improvement prioritization, subsystem life cycle management, standard operating procedures development, and job qualification requirements program authorship.

What research is on deck for the Kraken? Naval Medical Research Unit-Dayton is partnering with two other organizations on three separate planned research efforts for fiscal year 2018 and beyond. The first project is a NASA-led study of the loss of aircraft state awareness in commercial aviation. The second and third projects are Defense Health Agency-funded, Joint Program Commision-5 (Aviation Mishap Prevention Working Group)-sponsored SD research studies. Dr. Henry Williams, senior research psychologist at Naval Medical Research Unit-Dayton, is the lead on both of the latter projects. Williams investigates pilot SD modeling and will be looking at the effects of helmet-mounted display format and spatial audio cueing on pilot performance and SD prevention. ✈️

About the author:

Capt. Folga is the Disorientation Research Device program manager and currently serves as the engineering and technical services department head at the Naval Medical Research Unit-Dayton.



The author is strapped in prior to a test of a man-in-the-loop mode where subjects can control the device from inside the capsule. Photo by Megan Mundersbach

Photo courtesy of Environmental Tectonics Corporation

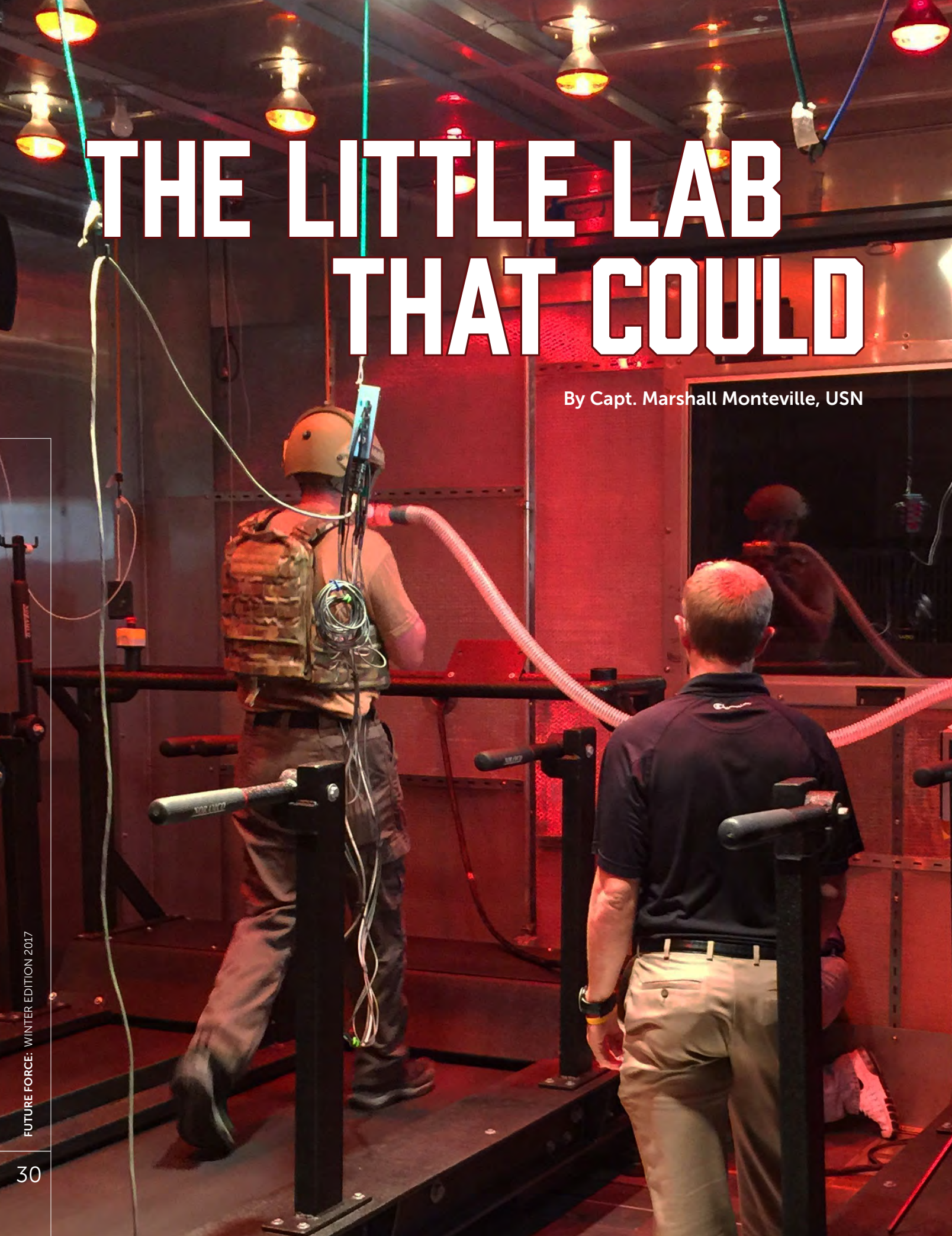


Photo by Regena Kowitz

THE LITTLE LAB THAT COULD

By Capt. Marshall Monteville, USN

THE NAVAL HEALTH RESEARCH CENTER IS ENGAGED IN A WIDE RANGE OF RESEARCH PROJECTS THAT SEEK TO MAINTAIN THE FLEET AND FORCE AT PEAK HEALTH AND READINESS.

With an initial budget of \$30,000 from the Navy's Bureau of Medicine and Surgery, furniture and office equipment supplied from a nearby Navy confinement facility, and a mission "to conduct research in neuropsychiatry as it applies to naval service," the Naval Health Research Center (NHRC) was commissioned on 1 June 1959.

Originally named the Navy Medical Neuropsychiatric Research Unit (NMNPRU), one of the command's first assignments was to conduct research in support of screening scientists and support personnel for Operation Deep Freeze, a joint scientific research effort in the Antarctic, supported by the Navy and directed by the National Science Foundation. Dr. Eric Gunderson, who would eventually become one of NHRC's scientific directors, conducted a series of psychological studies on Deep Freeze personnel, enabling him to successfully develop predictors for prospective candidates who would adjust well to Antarctica's challenging environment.

Another major focus of NHRC's early research was the study of the psychological aspects of sleep and its impact on performance. These studies were led by Dr. Laverne Johnson, who also would go on to become scientific director at NHRC and a noted sleep research pioneer.

Evolution and Expansion

Over the next decade and a half, NHRC's mission evolved and expanded. By 1974, NMNPRU had been renamed the Naval Health Research Center in recognition of the broader scope of its research programs. The command's new mission was "to conduct research and development on the medical and psychological aspects of health and performance of naval service personnel."

The year 1974 also saw the launch of the Center for Prisoner of War Studies at NHRC, now located in Pensacola, Florida. The center was established to examine the health and psychosocial effects of captivity and being subjected to severely inhumane conditions, including torture, among returning Vietnam service members.

Today, NHRC is housed in 24 historic military barracks that have been renovated into state-of-the-art laboratories and research facilities aboard Naval Base Point Loma, overlooking San Diego Bay. The lab's core research

areas are operational readiness and health, operational infectious diseases, and military population health, all focusing on the total health and readiness of warfighters and their families.

NHRC has a long and illustrious history of conducting research that innovates and flexes to meet the needs of our operational forces. Our scientists align our research with fleet and force requirements as we look ahead and anticipate the challenges our Navy and Marine Corps team will face in future battlespaces.

NHRC's core competencies today include physical health and wellness; psychological and behavioral health; injury, injury prevention, and rehabilitation; physical and cognitive performance; medical modeling and decision support; and infectious diseases surveillance and research.

Operationally Ready

Readiness is why we exist. Every research project is geared to improve warfighter performance or find solutions to health-related problems that impede readiness. Whether we're investigating methods for improving survivability and optimizing human performance or improving our data science capabilities to support medical and logistical decision-making, readiness is what we do.

Within NHRC's operational readiness and health division, scientists in the warfighter performance department conduct studies designed to keep service members in top physical and fighting shape by investigating innovative methods to maximize performance, boost resilience, and prevent injuries to keep warfighters healthy and medically ready.

But injuries do happen and operational tempos ramp up, which is why our researchers also study topics that include methods for improving rehabilitation therapies for wounded warriors and reducing the negative effects of fatigue and limited sleep. Research projects that address warfighter performance include identification of objective neuromarkers of performance through electroencephalogram (EEG) measurement; characterization of physiological and physical changes in special operators while training and operating underwater; modification of Navy shipboard physiological heat exposure limits; and evaluation of targeted, novel vestibular rehabilitation programs for traumatic brain injuries.

To support this research, NHRC is home to the Warfighter Performance Laboratory, a 6,000-square foot human performance laboratory with capabilities that include: the Computer Assisted Rehabilitation Environment, an immersive virtual reality system with visual, auditory, vestibular, and tactile sensory inputs; a two-bedroom sleep and fatigue laboratory; and an environmental chamber with a temperature range of -23 to 130 degrees Fahrenheit.

The lab allows scientists to conduct a range of studies, all under one roof, to address the challenges faced by modern warfighters, including fatigue, heat stress, musculoskeletal injury, and diminished cognitive performance. Being colocated enables NHRC’s multidisciplinary scientists—physiologists, biomedical engineers, and neuroscientists—to collaborate. The research possibilities are only limited by their imagination.

Operationally relevant medical research at NHRC is about more than just muscle and bones—it’s also about bytes and bits. For more than 35 years, NHRC has been refining its expertise in managing “big data.”

The medical modeling, simulation, and mission support team analyzes large volumes of data and develops medical planning, logistics, and decision support tools.

Data analysts who focus on expeditionary medical research collect and scrub data from numerous medical, operational, and tactical datasets and integrate it into the Expeditionary Medical Encounter Database (EMED), a comprehensive repository created by NHRC scientists. Current research projects include investigation of extremity trauma to maximize health and quality of life outcomes, and the study of blast-related outcomes in the auditory system to mitigate injury and improve outcomes

NHRC’s data scientists also have developed software tools to support operational readiness by providing military line and medical leaders with validated, science-based methods for making informed decisions that improve survivability and long-term health outcomes for injured and ill service members. These tools, which have been validated and accredited by the Department of Defense and use EMED as a foundation, include the Joint Medical Planning Tool and the Medical Planners Toolkit.

No matter where the mission takes our military, the tools developed by NHRC researchers provide accurate and reliable information to decision-makers, ensuring our warfighters receive the right care and treatment at the right time and in the right place.

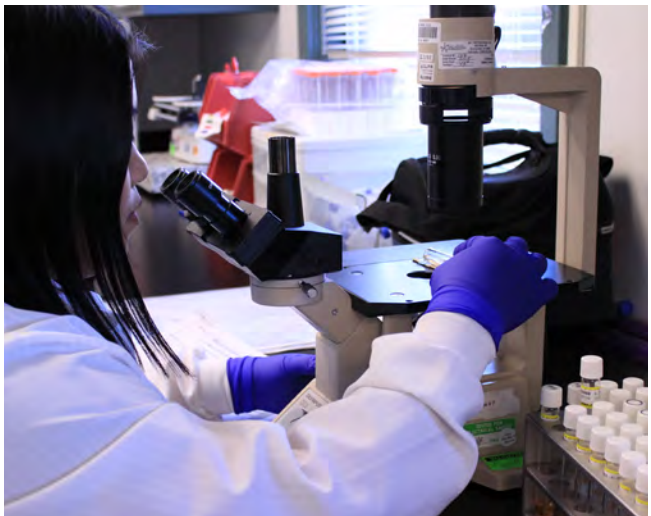
Healthy Military Populations

Beyond the battlefield, understanding the health effects, physical as well as psychological, of military service in the near and long term is an important component of maintaining readiness. NHRC researchers do this by investigating risk and resilience factors that impact the health and wellness of service members and their families.

Our military population health research is key to improving the overall health of our warfighters and military families. NHRC partners with other military services, the Department of Veterans Affairs, industry leaders, and academia to conduct long-term health studies, develop appropriate health surveillance strategies, and create and evaluate health and wellness programs and products. Being proactive by using research to understand the factors that impact health, allows us to improve overall readiness by targeting those factors that promote physical and mental resilience and mitigating the ones that pose health risks.

Since 1999, NHRC has been designated the Department of Defense’s deployment health research center. Researchers on the deployment health team conduct many leading epidemiological and behavioral health studies and they are responsible for several longitudinal studies, including:

- **The Millennium Cohort Program:** This is the largest prospective health study in Defense Department history and investigates how military occupational exposures, including those encountered during deployments, affect the long-term health of service members.
- **Millennium Cohort Family Program:** The first longitudinal study to follow a population-based cohort of military spouses and assess the long-term effects of military service and deployment on family health.
- **The Recruit Assessment Program:** This program collects baseline health data and preservice exposures from Marine recruits to understand how military service affects health outcomes. Data collected is being used to inform early intervention and prevention programs to protect health and readiness.
- **Reproductive Health Research:** These studies, which include the birth and infant health registry, evaluate reproductive health outcomes in relation to specific military exposures such as vaccines and those related to deployment, occupation, or geographic location.



The operational infectious diseases microbiology laboratory is separated into two sections, virology and bacteriology. The research team conducts basic and applied biomedical research to improve force health protection and mission readiness. Photo by Regena Kowitz

The long-term health of warfighters is important, but NHRC’s health and behavioral sciences team also is working to address some of the more immediate challenges our warfighters face. Researchers are studying clinical treatments that address the unique needs of military members, health promotion interventions to improve health and resilience, and risk factors for psychological and behavioral health problems. Current research projects include the development and evaluation of a novel treatment for service members with comorbid post-traumatic stress disorder and major depressive disorder, development of self-guided workbooks to help service members reduce stress, development of a mobile app to reduce prescription drug misuse, and the creation and validation of improved suicide screening tools for healthcare providers

One of the best things about being a Navy researcher is knowing the work we are doing is having a direct and positive impact on our warfighters. Our work isn’t theoretical, it’s practical. The work we do in the lab is translated into practical tools and interventions and put to work to improve warfighter health.

Fighting Infectious Diseases

Often, the biggest threats to the health and readiness of the US military aren’t bullets or roadside bombs—they’re microscopic organisms that can spread from person to person like wildfire.



The Naval Health Research Center conducts research using the Computer Assisted Rehabilitation Environment (CAREN), an immersive virtual reality system. The CAREN is made up of a 9-foot diameter platform with integrated treadmill and 180-degree wide, 9-foot tall curved projection screen. The CAREN is used for studies related to survivability, equipment loads, rehabilitation, and fatigue. Photo by Regena Kowitz



Aerial view of the Naval Health Research Center, located at Point Loma in San Diego, California.

These tiny pathogens—viruses and bacteria—cause illness and death without discrimination, decimating the readiness of individuals and entire units. Before World War II, more warfighters were lost to disease than combat. But science has turned the tide in this battle and NHRC scientists are on the front lines of this fight.

The basic and applied biomedical research we're conducting is critical to force health protection and mission readiness. Our military operates globally, serving in areas of the world where they may be exposed to endemic infectious diseases. Many of our Sailors and Marines also live in close quarters—in barracks and shipboard berthing spaces—making them vulnerable to contagious illnesses, like influenza and norovirus. Disease outbreaks, especially in an operational environment, can compromise the mission. Our job is to see that it doesn't.

NHRC's biosurveillance team's research serves as an early-warning system for dangerous pathogens and potential pandemics. Scientists at NHRC continually monitor for the presence of infectious diseases in military populations. When researchers find a potential disease threat, they alert leaders within the military and civilian

medical communities so they can take action to prevent or contain disease outbreaks.

The team has a proven track record of doing just that. In 2009, scientists at NHRC conducting routine respiratory surveillance on samples collected from clinics in Southern California identified two influenza A cases that were different. They didn't sub-type as either of the seasonal strains in circulation at the time. Researchers had identified the first cases of the H1N1 pandemic. Early identification allowed public health authorities to respond to the outbreak quickly.

The team's current research includes ongoing respiratory and acute gastroenteritis surveillance, enteric bacterial antimicrobial resistance, evaluation of diagnostics for clinical and field use to rapidly detect illness, and improved treatments for endemic and pandemic influenza.

Researchers within NHRC's clinical studies department support the health and readiness of the Navy and Marine Corps by conducting clinical trials that target diseases that affect warfighters, including adenovirus, norovirus, and shingles. Through clinical studies and ongoing research,

scientists further understanding of these diseases to advance diagnostic capabilities and disease prevention measures such as new and improved vaccines and treatments.

One success story involved the vaccine for adenovirus. After the vaccine was discontinued in the mid-1990s at recruit training commands throughout the Defense Department, research done by NHRC helped get the vaccine reinstated in 2011, dramatically reducing rates of adenovirus among recruits—cases went from 250 each week to two. This work has positively affected recruit training by reducing the number of training days missed because of illness.

Currently, NHRC's clinical studies team also is evaluating the effectiveness of the first norovirus vaccine in reducing outbreaks of acute gastroenteritis; a novel test (dried blood spot matrix) for assessing immunogenicity of a variety of vaccines; meningococcal carriage studies to understand why military recruits have higher risk for meningococcal disease; and an analysis of the incidence of varicella (chickenpox) and shingles in military populations to inform vaccination schedules and potential modification to reduce rates of shingles.

The Future

From its humble beginnings, the scientific studies conducted by NHRC researchers have contributed to improved health and readiness not just for Sailors and Marines, but also for the rest of the Defense Department and even the civilian community.

In charting a course for the future, NHRC will continue to lean forward, maintain an agile mindset, and align research activities with the needs of warfighters in the fleet and on the field to enhance their health and readiness, increase their survivability, boost their resilience and recovery, and help them operate at the pinnacle of human performance. ✈

About the author:

Capt. Monteville is the commanding officer of the Naval Health Research Center.



HC1 Harold Sylvester, assigned to Naval Medical Research Center Asia, sets and baits mosquito traps in Singapore. The center is conducting research to study the different populations of mosquitos in Singapore and their ability to transmit diseases. Photo by MC1 Jay C. Pugh

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