Mini-Symposia Title:

Engineering and Medicine in Extreme Environments - Part II

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Mini-Symposia Speaker Name & Affiliation 3:

Alistair McEwan, The University of Sydney

Mini-Symposia Speaker Name & Affiliation 4:

Laura Brattain, MIT Lincoln Labs

Theme:

- ○ 01. Biomedical Signal Processing
- ○ 02. Biomedical Imaging and Image Processing
- ○ 03. Micro/Nano-bioengineering; Cellular/Tissue Engineering &
- ○ 04. Computational Systems &Synthetic Biology; Multiscale modeling
- ○ 05. Cardiovascular and Respiratory Systems Engineering
- ○ 06. Neural and Rehabilitation Engineering
- ● 07. Biomedical Sensors and Wearable Systems
- ○ 08. Biorobotics and Biomechanics
- ○ 09. Therapeutic &Diagnostic Systems and Technologies
- ○ 10. Biomedical &Health Informatics
- ○ 11. Biomedical Engineering Education and Society
- ○ 12. Translational Engineering for Healthcare Innovation and Commercialization

Mini-Symposia Synopsis— Max 2000 Characters

Extreme environments, such as naturals (underwater, altitude, space, geographic poles, volcanoes, desert,…) or forced/man-made (extreme sports, emergency forces, armed forces) are conditions where specific physiological adaptations in the human body are triggered to maintain physiological functionality and to ensure survival.

The general goal in the medical and engineering areas can be formulated as: to enhance human comfort, performance and survival in extreme environments.

The Mini-Symposia will present world-leading experts in varying research fields ranging from engineering and medicine in diving, space, tactical forces and other extreme environments to present on their current research fields of device engineering, computer science and medical application scenarios.

This Mini-Symposia is Part II of two Mini-Symposia in Engineering and Medicine and Extreme Environment at the EMBC’20 Montreal, in combination with a Mini-Symposia Engineering and Medicine in Extreme Environments Part I which is also proposed and organized by T. Cibis, C. McGregor

Controlled Climates for Pre-Deployment Acclimation

Brendan Bonnis, Carolyn McGregor

Abstract— **Military personnel deployments can be to environments with extreme climate conditions. This paper presents research for extreme climate pre-deployment acclimation resilience assessment using climate chambers, big data and artificial intelligence generated analytics.**

I. Introduction

Military personnel are deployed internationally and they will face different climatic conditions during deployments including conditions of extreme cold or heat and humid or dry environments. Military personnel can complete pre-deployment acclimation training in a location with a similar climate to build resilience to the climate where they will be deployed. Natural environments cannot be controlled or repeated. While some locations can present fairly consistent weather, exact conditions cannot be controlled. Use of remote natural locations can present risks to participants if medical incidents occur and immediate medical attention is required necessitating significant logistics to support the training activity. Prior research on acclimation has focused on general exposure and fitness training in natural environments or small thermal rooms. Malgoyre [1] performed heat acclimatization research in French Army soldiers through training in desert like conditions near Abu Dhabi in United Arab Emirates.

Early acclimation research in human subjects dates back to the late 50's [2]. Although studies have been performed on acclimation in extreme heat and extreme cold, the focus has been on post analysis of data for population based studies [1]–[4] rather than the creation of personalized acclimation assessments proposed in this proposed solution. Malgoyre et al [1] note that full acclimation for military personnel can be achieved after 15 days, however, research in acclimation for athletes and public safety personnel wearing personnel protective equipment (PPE) have reported 5-6 days of repeated exposure creates the most incremental adaption response after which, the degree of incremental change diminishes significantly [2]–[4].

In prior research McGregor created an artificial intelligence based Big Data analytics platform, Athena, for personalized resilience assessment and development and demonstrated its potential for use in tactical operator training integrating physiological data with ArmA 3 first person shooter game data [5]. To create the training scenarios for that research, she collaborated with Canadian veteran and paramilitary specialist Bonnis [6] to propose a method to structure individualized trainee resilience assessment and development in response to a structured set of stressors. They extended that research [7] to demonstrate the use of Athena to retrospectively assess firefighter student physiological response during a brief search and rescue activity in 50^{o}C in one of the ACE Facility climatic chambers.

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II. Extreme Climate Pre-deployment Acclimation Resilience Assessment Using Climate Chambers and Big Data

This research utilizes the one of a kind climatic weather chambers within the $190 million Ontario Tech ACE Facility. Deployment scenes were established within an interconnected space made up of ACE's climatic wind tunnel (CWT), large climatic chamber (LCC), small climatic chamber (SCC) and the Transfer Bay that connects them. The LCC contained a two storey structure to facilitate search scenarios. Two hour extreme cold deployment simulations were completed at -20C and six hour extreme heat deployment simulations were completed at 50C. The extreme heat simulation included use of a transportation vehicle in an additional room with a 4 post shaker to simulate transport. Physiological, climatic and activity data was captured and analysed by Athena.

References

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[7] C. McGregor, F. M. Williams-Bell, and B. Bonnis, "Using Streaming Big Data for Resilience Assessment within Pre-service Firefighter Extreme Condition Training," in *The 9th annual Military and Veteran Health Research Forum (CIMVHR)*, 2018, p. 29.

Utilizing Physiology for Scuba Diving Technology

Tobias Cibis

***Abstract*— Historically, diving evolved from two different approaches. Firstly, the development of diving equipment to pursuit greater depths and underwater time. Secondly, the understanding of underwater physiology and medicine. Most common diving technologies and their applications are based on empirical determinations of pathological occurrences due to diving activates. Real-time measured physiological data are not accounted in algorithms which aim to step divers safely back towards the surface. Considering a potential application of physiological data may individualize diving technology, such as the diving computer for a diver.**

III. Introduction

The development of diving gear, such as diving bells, helmets that are provided with air via surface-air supply and eventually the SCUBA (Self-Contained-Breathing-Apparatus) gear opened the underwater world for exploration. Depth limits were pushed to greater depths and diving time was increased significantly. This resulted in new physiological challenges and problems that where previously unknown.

While reaching greater diving depths, the effects of nitrogen narcosis and oxygen toxicity were discovered. These effects manifest from increased oxygen and nitrogen partial pressures and the dissolvent of these gas in bodily fluids and tissue and commonly result in cognitive impairment or worse. Furthermore, breathing compressed air in high ambient pressure conditions was eventually linked to physical gas kinetics that occur within the body. This is known as decompression illness, which describes the formation of nitrogen bubbles in blood and tissue which may have lethal impact on human life.

To conquer the onset of decompression illness, decompression schedules were design using tables and algorithms. However, these tables and algorithms only rely on time, depth and environmental data.

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IV. Diving Technology and Physiology

The two most common approaches to provide safety for divers are decompression tables and diving computers which incorporate decompression algorithms. Through out multiple studies, the first decompression tables were introduced by John Scott Haldane and colleagues. Empirically determined, these tables suggest time intervals for duration at depth, ascent times and decompression intervals.

Derived from these tables, decompression algorithms calculate decompression schedule in real-time relying on time, depth and environmental information. In addition, these algorithms take bubble growth and elimination into account by predicting gas kinetics. The calculations utilize biological, chemical and physical process for time interval determination. All processes are well studied and reproduced in laboratory settings. However, the impact of physiology which may alter these processes are unknown.

V. Physiology Application

Considering modern decompression algorithms, the opportunity may come to hand, that physiological parameter such as heart rate, blood pressure and electro dermal activity may provide information to extend existing algorithms and thereby individualize the diving computer for the diver.

References

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Bio-Inspiration from Extreme Environments

Alistair McEwan, The University of Sydney and Tobias Cibis

Abstract— **Many engineering designs have taken inspiration from biology leading to faster and better design time and effort. We consider which animals could be linked to physiological monitoring with a focus on bioelectronic signals.**

VI. Introduction

Engineering and design have often taken inspiration from biology and nature. Famous examples are based on the interesting and extreme capability of animals and include the development on Velcro from the hook structure on burrs that attach to fur, coatings to mimic the microstructure of colorful butterfly wings, the shape of train engines based on bird beaks and wind generator fins with corrugated edges based on those of whales. These can be classified and placed in a systematic framework based on needs or curiosity to reduce design time and effort [1].

VII. Bioelectric Signal Inspiration

Physiological monitoring inspiration can be taken from electric fish such as sharks and rays that live in extreme ocean environments and use passive electroreception in the range of 5-500uV/cm to sense prey (Fig. 1). Monotremes in the harsh Australian environment including the platypus and echidna appear to have evolved independently with different levels of brain innervation and processing, dipole source direction finding, primary nerve endings, and common mode rejection based on electroreceptor positioning [2]. They can sense in the range of 0.3-2mV/cm to detect prey in muddy streams or the very dry desert sand. These electrical senses can be compared to bioelectric sensors such as the widely used EKG or ECG and by better studying these animals we can build improved physiological sensors and systems. The platypus also displays a mechanical transducer on its duck like bill that can be compared to the mechanical physiological monitors such as the stethoscope or ultrasound. Interestingly it appears to use the electrical and mechanical signals in a combined fashion. Weakly electric fish found in freshwater rivers and lakes in Africa and the coffin ray found in saltwater both use active electroreception to sense the change in electrical properties or electrical impedance in their environment [3]. The biophysical mechanism, signal processing and algorithms used by these creatures may be used to better design physiological monitoring systems, medical devices and life support systems both in conventional settings such as clinics and exploration in extreme environments.

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Ultrasound Technology in Extreme Environments

Laura Brattain, MIT Lincoln Labs

***Abstract*— Expeditions in extreme environments such as high altitude, deep water, and space can create potentially life-threating physiological complications. Medical ultrasound is a leading diagnostic modality, sometimes the only modality, used in these environments. In this talk, I will start with a survey of ultrasound applications in extreme environments, followed by discussions on how advances in artificial intelligence and wearable technology can potentially enable automated, accurate, and continuous phycological monitoring using ultrasound.**

VIII. INTRODUCTION

Expeditions in extreme environments such as high altitude, deep water, and space can create physiological complications. If not monitored properly, adverse reactions can be life-threating. For example, high altitude environment often introduces hyperventilation, hypoxia-induced anorexia, dyspnea, and severe headache. Acute mountain sickness can cause high-altitude cerebral edema and pulmonary edema. Exposure to underwater environment creates a number of physiological risks as a result of the hyperbaric underwater environment: the toxic effects of hyperbaric gases, the respiratory effects of increased gas density, drowning, hypothermia and bubble related pathophysiology. Spaceflight can have a significant negative effect on an astronaut's cardiovascular physiology, muscle health, vision, and bone density.

IX. APPLICATION OF ULTRASOUND IN EXTREME ENVIRONMENTS

Owning to its portability, non-ionization, and the ability to produce real-time diagnosis, medical ultrasound is a leading diagnostic modality, sometimes the only modality, used in extreme environments. Lung ultrasound can accurately diagnose high-altitude pulmonary edema. Doppler ultrasound is used to assess pulmonary hypertension as well as to detect intracardial gas bubbles during decompression to altitude or hyperbaric chamber. Echocardiography is widely used to access cardiovascular fitness among those who have been exposed to extreme environment. Ultrasound has also been used to measure optical-nerve sheath diameter, a biomarker used to evaluate changes in intracranial pressure as a result of long duration space flight, acute mount sickness, or hypobaric hypoxia. Spinal ultrasound provides essential anatomic information in monitoring changes in the lumbar and sacral spine as a result of exposure to microgravity in astronauts.

X. FUTURE OPPORTUNITIES

Despite of the advantages of ultrasound over the radiographic capabilities such as X-ray and CT, ultrasound diagnosis is highly operator dependent and suffers from high intra- and inter- observer variability. In extreme environments, there is often a lack of medical expertise, which greatly limits the utility of ultrasound. Recent advances in artificial intelligence (AI) has shown promise in improving the automated and objective interpretation of ultrasound, thus assisting nonexpert use. Wearable technology can enable the capability of continuous physiological monitoring using ultrasound. Progress in both areas will be reported.

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