Closed-Loop Neuro-Physical Interventions for Real-Time Performance Recovery Under Extreme Thermal Stress in Military Firefighters

Kenneth J. Loh [1,*], David Sten [2], Regan Wareham [2], Taylor Pierce [1], Xinyi Yang [2], and Shih-Chao Huang [2]

[1] ARMOR Lab and Center for Extreme Events Research (CEER), University of California San Diego
[2] S10 Neuro, San Diego, CA
*Corresponding E-mail: kenloh@ucsd.edu

ACTIVE, RESPONSIVE, MULTIFUNCTIONAL, AND ORDERED-MATERIALS RESEARCH (ARMOR) LABORATORY

The Problem

- Military and civilian firefighters operate under **extreme thermal and physical conditions**
- Stressors degrade **reaction time, coordination, and decision-making**, increasing injury risk
- Real-time firefighter **health, physiological, and performance conditions unknown**
- Current **recovery** practices rely on **passive rest**

Objective

- Develop a **closed-loop Sense-Interpret-Prime-Act system** for enhancing firefighter performance and recovery
  - Monitor firefighter **health and activity**
  - Integrate **sensors** with firefighting ensemble (FFE) and gear
  - Identify individual **physiological degradations**
  - **Enhance and shorten recovery** with simple interventions

Approach

- **Nanocomposite physiological sensors** designed to be worn on the body or integrated with FFE
- **Multi-modal sensing** with novel and commercial off-the-shelf sensors
- Designed and tested short, simple, **neuro-physical interventions**
- Conducted **field validation study** at Naval Submarine Base Kings Bay with 10 Navy firefighters

Structured neuro-physical interventions could rapidly restore cognitive, physiological, and motor performance following extreme heat stress

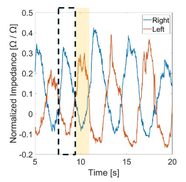
Multi-Modal Sensing with Novel and Commercial Sensors:

- Nanocomposite strain sensors for **respiration and gait monitoring**
- Custom wireless Bluetooth/WiFi printed circuit board (PCB) with **inertial measurement unit (IMU)** and **ambient temperature sensors**
- Calera Core™ **core body temperature** and Polar Pro™ **heart rate**

Textile strain sensors

Elastomer pressure sensors

Gait Monitoring

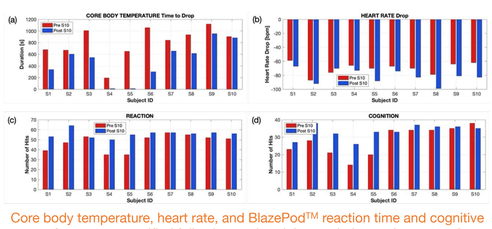


Right and left pressure sensors measured gait during walking

- Polar Pro™ Heart Rate Monitor with strap
- Calera Core™ core body temperature sensor
- Nanocomposite respiration patch
- Custom PCB for data acquisition and IMU

Field Validation Study at Naval Submarine Base Kings Bay:

- 10 subjects underwent **repeated heat exposure and live-fire training**
  - Pre-S10: **no intervention** & standard 15-min passive recovery
  - Post-S10: **intervention** before 2nd training & during 15-min recovery
- Data from BlazePod™ assessment and wearable sensors examined



Core body temperature, heart rate, and BlazePod™ reaction time and cognitive performance quantified following each training evolution and compared

The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the University of California San Diego Institutional Review Board Protocol Number 806354.

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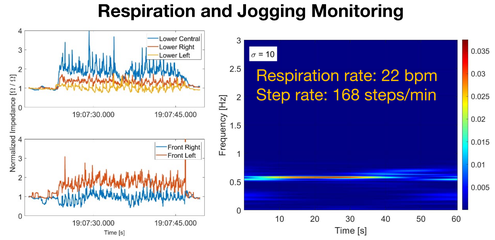
SENSE **INTERPRET**

ACT **PRIME**

Characterize Physiological Conditions and Degradation:

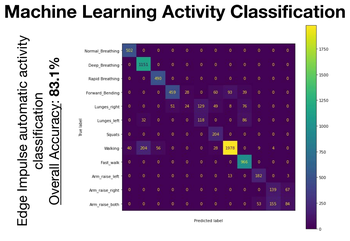
- Signal processing algorithms **identify relevant physiological features** from multi-modal sensor signals
- Algorithm individually trained on specific user data to **identify movement anomalies and performance degradation**

Respiration and Jogging Monitoring



(Left) SCBA nanocomposite strain sensor time history responses and (Right) wavelet transform identified two dominant frequencies of interest

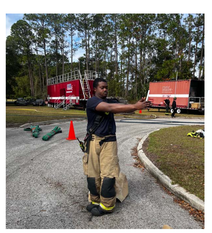
Machine Learning Activity Classification



Confusion Matrix shows accurate prediction of different breathing rates, fast walking, and squats

Apply Relevant Neuro-Physical Intervention:

- Neuroscience underpins a warfighter's every thought, movement, and decision
- Neuro-Physical Interventions: use of nervous system principles to improve performance by **targeting the systems that receive input, integrate information, and produce output**
- Use movement, breathing, gaze control, tactile input, proprioceptive mapping, visual vestibular orientation, grip awareness, rhythm, task specific coordination, dosing, and reassessment
- Target these systems through **rapid drills**



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