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Project AURORA-HFSM: Autonomous Ultrasound & NIRS Rig for Orbital Redistribution Assessment

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INTRODUCTION & AIM

In microgravity, fluids shift toward the head that change in fluid distribution leads to an increase in pressure of the skull. Roughly two liters of fluid move from the lower limbs toward the chest and head. These changes can induce medical issues such as optic nerve swelling, increase in intracranial pressure and facial edema. Current medical diagnostics although advanced, lack a holistic approach.

Neurological effects have been documented across multiple papers shedding light on impacts on human performance including changes in white matter, free water, ventricular volume. The latter being one of the probable causes of Spaceflight Associated Neuro-Ocular Syndrome, a condition that affects 50% of astronauts. On orbit research and medical monitoring of fluid distribution can potentially give the key answers on the mechanism of fluid redistribution.

The overall goal of our project is to demonstrate how integrating multiple medical technologies and electronic devices can provide a multimodal monitoring and diagnostic while helping to understand Spaceflight induced conditions such as Spaceflight Associated Neuro-Ocular Syndrome and headward fluid redistribution.

Technology we aim to use: **Multimodal Monitoring Rig**
Cerebrovascular Tracking: Ultrasound (US) & Near-Infrared Spectroscopy (NIRS).
Fluid Redistribution: Indocyanine Green (ICG) tracking.
Motion Correction: Inertial Measurement Units (IMU) for motion synchronisation.
Data Integration: Signals recorded continuously and synchronised to provide a unified dataset of jugular, cerebral, and thoracic dynamics.

METHOD – Zero G

Platform: Airbus A310 Zero-G (ESA Parabolic Flight Campaign).
Parabolic Profile: 31 parabolas per flight.
Gravity Phases:
- **1.8 g** (Pull-up/Hyper-gravity)
- **0 g** (Microgravity – ~22s per parabola)
- **1 g** (Recovery)

Cumulative Data: ~11 minutes of total microgravity exposure per flight.

Current PRISMA status:

Simultaneously, we are conducting a systematic review.
Working title: Wearable Sensors for Monitoring Haemodynamics, Tissue Perfusion, and Motion in Microgravity.

Used PubMed (n= 2,671) and Cochrane Library (n= 781).
Screening will be dual-blinded in Rayyan.

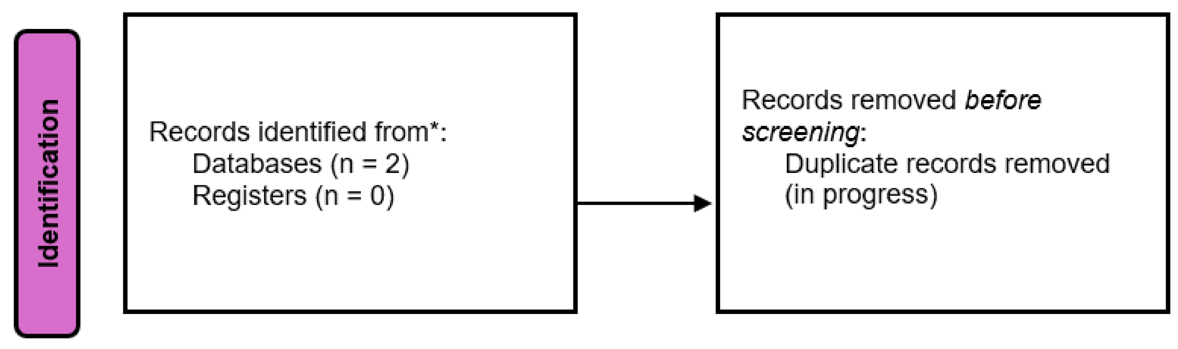

Figure 1: *PRISMA flow diagram showing the literature selection process.*

EXPECTED OUTCOMES & COMPLIANCE AND SAFETY

The AURORA-HFSM experiment will provide new quantitative data on cerebrovascular and intracranial fluid shifts in microgravity, improving understanding of SANS and supporting astronaut health countermeasures. It will also validate portable cerebral monitoring systems for space and Earth-based clinical use.

Using synchronized ultrasound, NIRS, ICG, and IMU during parabolic flights, the study will measure venous and arterial flow, oxygenation, and headward fluid shifts in 0 g conditions. Key outcomes include IJV flow changes, correlations between cerebral oxygenation and ICP surrogates, identification of microgravity hemodynamic patterns, and validation of multimodal data fusion methods, producing a time-aligned dataset for ESA space physiology research.

- Quantitative characterization of cerebrovascular and intracranial fluid shifts in microgravity
- Identification of hemodynamic patterns linked to Spaceflight-Associated Neuro-ocular Syndrome (SANS)
- Validation of a multimodal monitoring system combining US, NIRS, ICG, and IMU
- Improved understanding of cerebral perfusion and oxygenation changes in altered gravity
- Development of integrated biomarkers for astronaut health monitoring
- Extension to emergency medicine use cases, including emergency department and pre-hospital (ambulance) settings, enabling rapid, point-of-care assessment of cerebral perfusion and oxygenation to support early triage, timely diagnosis, and treatment decision-making in acute neurological and cardiovascular events
- Future work will further explore deployment of the system in emergency and pre-hospital environments, focusing on usability in time-critical conditions, integration with existing clinical workflows, and its potential to reduce time-to-intervention and improve patient outcomes

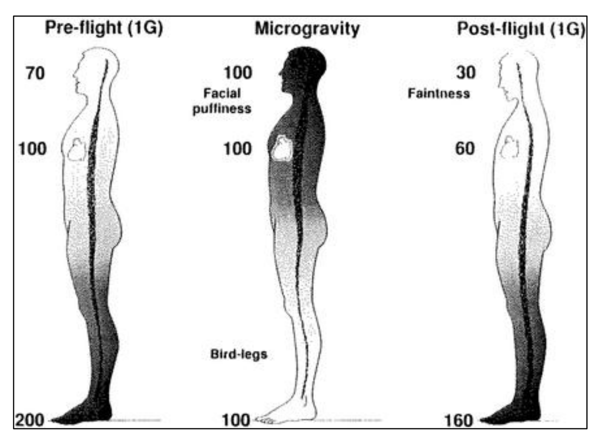

Figure 2: *Hypothetical arterial blood pressures in 1-G and microgravity (Source: Hargens and Richardson, 2009).*

Potential hazards were identified and evaluated following the ESA Safety Review Template. Each hazard was assessed for likelihood, mitigation strategy, and residual risk . All identified risks remain within acceptable ESA thresholds. Residual risks are minimized through hardware redundancy, conservative power design, and mechanical containment. The experiment involves no hazardous materials, pressurized components, or exposed conductive parts.

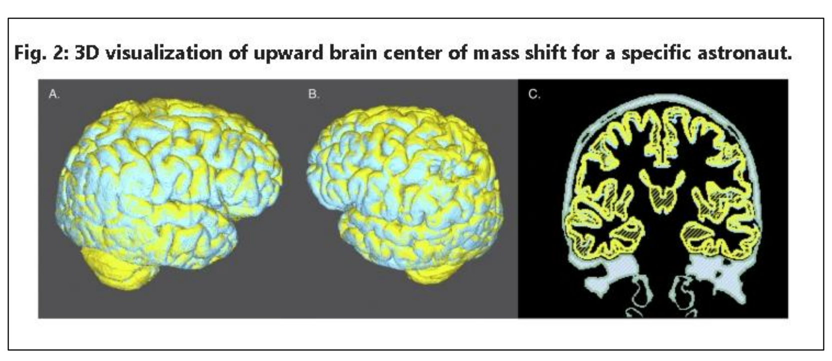

Figure 3: *3D visualization of upward brain center of mass shift (Source: Warthen et al., 2025).*

CONCLUSIONS

AURORA-HFSM introduces a novel multimodal system to study cerebrovascular fluid shifts in microgravity. The experiment will provide new insights into the mechanisms of Spaceflight-Associated Neuro-ocular Syndrome (SANS) by enabling real-time, integrated monitoring of cerebral hemodynamics.

Its portable and non-invasive design also shows strong potential for applications in clinical medicine, supporting diagnostics and monitoring in neurology and intensive care. Overall, AURORA-HFSM bridges space research and healthcare innovation, contributing to safer long-duration space missions.

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