Considerations for Health and Performance during Surface Extravehicular Activities

May 5, 2024

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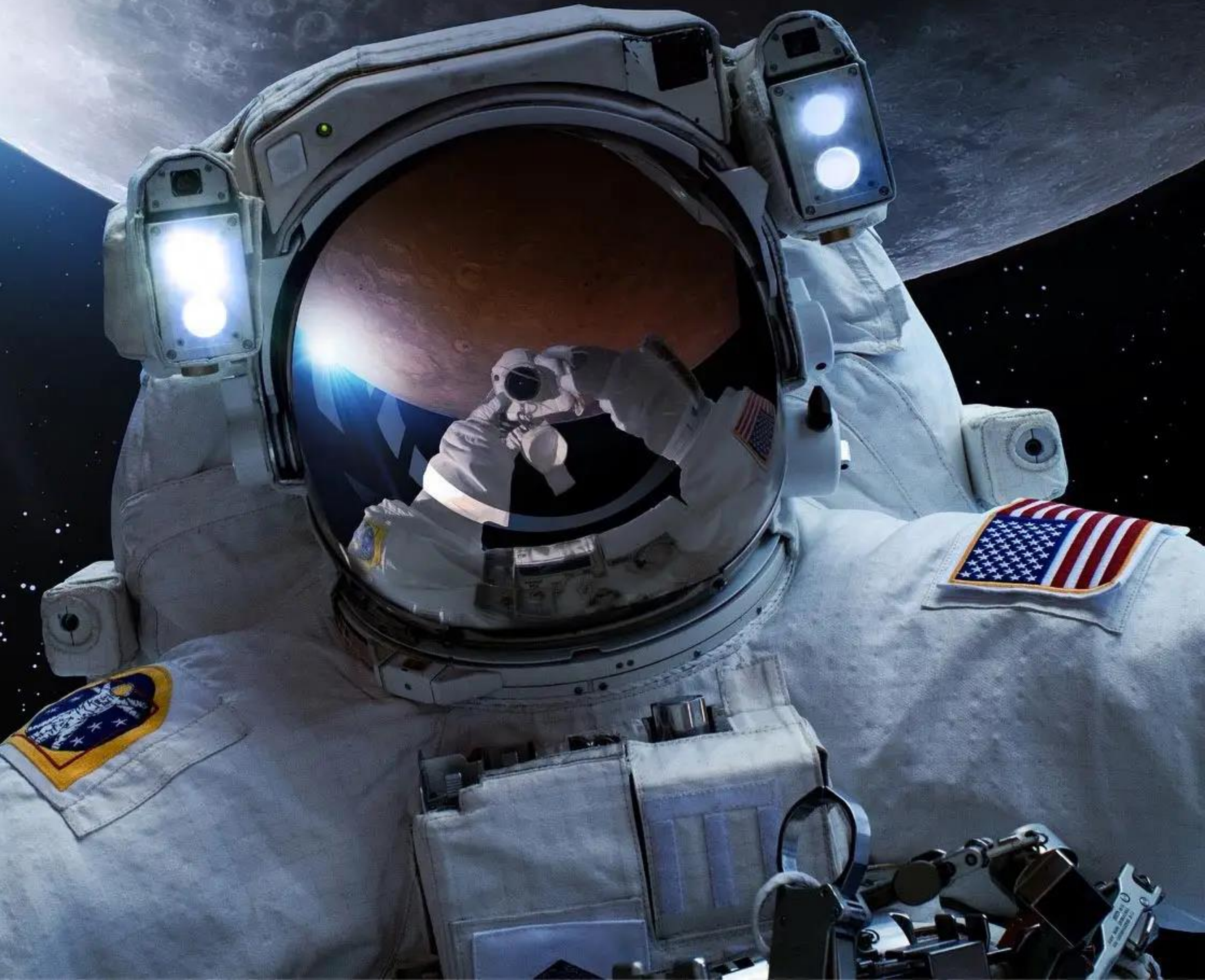

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The presented efforts were primarily funded by the following organizations:

- Extravehicular Activity and Human Surface Mobility Program (EHP)
- Mars Campaign Office (MCO)
- Human Research Program (HRP)

EVA: Microgravity vs. Exploration

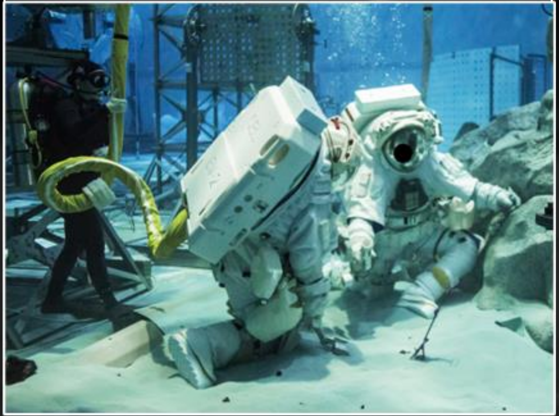
- **Increased physical & cognitive workload**
  - Effectively adding lower body into EVAs again
  - Increased autonomy, less mission support, especially for Mars
- **Additional injury mechanisms**
  - Lower body and back injuries more likely in Surface EVAs
- **Increased opportunities for injury and compromised performance**
  - Only three Apollo missions had back-to-back EVAs.
  - With reduced recovery time between EVAs (higher EVA density), possible fatigue and repetitive / cumulative effects become an increased concern
- **Uncertainty in Lunar Surface EVA ConOps, Equipment, and Tasks**
  - Limited number of relevant Lunar EVA physiological datasets.
  - Currently defining exploration EVA training pipelines and facilities

Parameter	Current ISS EVA	Exploration EVA
Tempo	8hrs EVA / ~ 2 months	**24hrs EVA / 1 week**
Environment	Engineered Completely Characterized Microgravity Uncontaminated	Natural & Engineered Incomplete Characterization Partial Gravity Dust
Tasks	Construction Maintenance	Science Construction Maintenance
Skills	Specific Skills/task-based	Generic Skills Specific Skills/task-based (Tool-based)
Mission	Specific tasks	Broadly scoped timelines Real-time adjustments *("Flexecution")*
Ops Support	MCC-centric Extensive personnel support	Crew-centric Delayed ground support

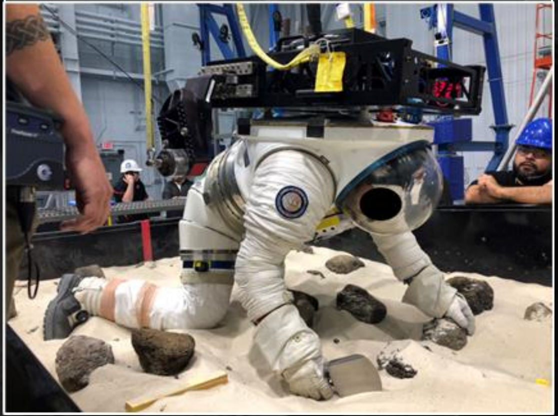
Future Exploration EVA will be quite different from ISS and Shuttle EVA, and even previous Apollo EVAs!

Key EVA Training, Simulation, and Test Environments

- **NBL**
  - Suit: Real
  - Offloading: 0g to 1g
  - Pros:
    - Dual-EV ops
    - Distributed offload
  - Cons:
    - Water (Sensors)
    - Water drag
    - Artificial stability



- **ARGOS**
  - Suit: Real
  - Offloading: 0g to 1g
  - Pros:
    - Easily accessible and configurable
  - Cons:
    - Only single-EV ops
    - Limbs not offloaded
    - Limited playspace



- **Field/Rock Yard**
  - Suit: Simulator
  - Offloading: None
  - Pros:
    - Realistic environment
    - Rover accessibility
  - Cons:
    - Power and data transmission

- **APACHE**
  - Suit: Simulator
  - Offloading: None
  - Pros:
    - Highly controllable
    - Immersion
  - Cons:
    - Technology-limited (e.g. haptics)
    - Limited space

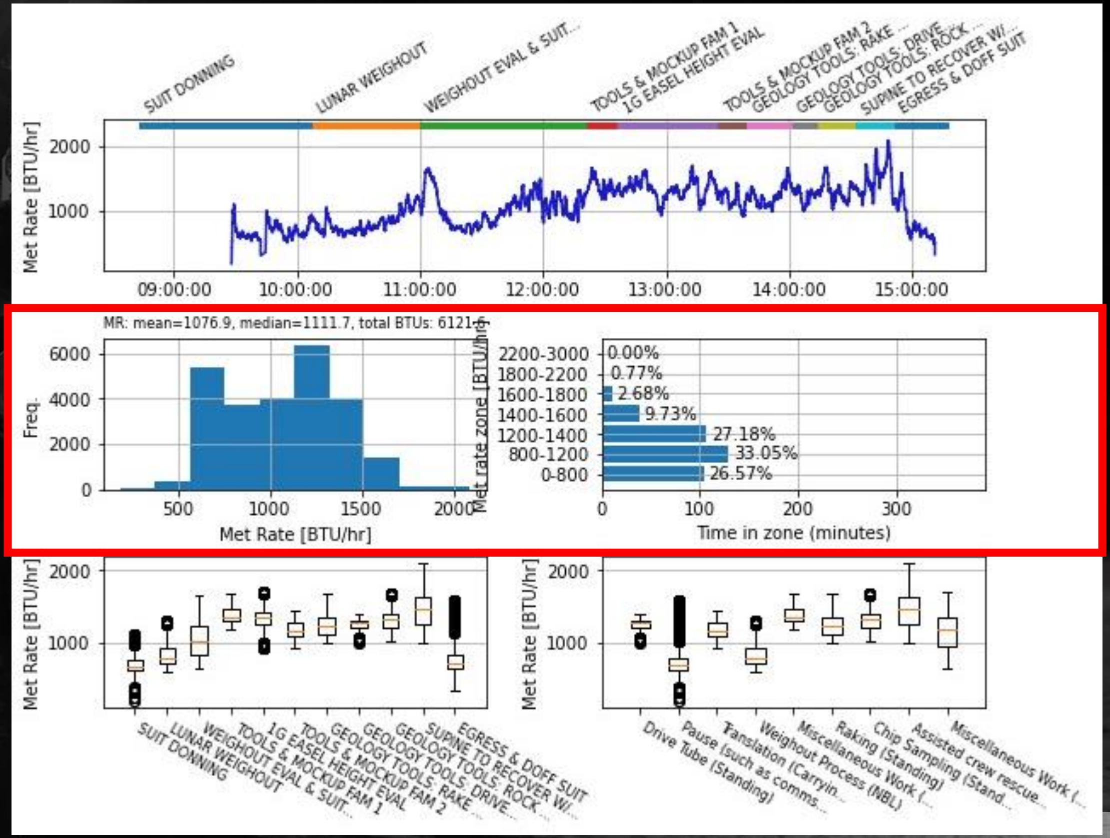
NBL = Neutral Buoyancy Lab

ARGOS = Active Response Gravity Offload System

APACHE = Assessments of Physiology and Cognition in Hybrid-reality Environments

NBL Lunar – Met Rate

- Physical workloads and associated metabolic rates have been observed approaching 60% of individual maximal capabilities for some tasks and motions.
- Workloads may be altered with different spacesuit designs or operating pressures.



Coan DA, et al. Extravehicular Activity (EVA) & Human Surface Mobility (HSM) Program (EHP) xEMU NBL Lunar Test Series 2.2 Executive Summary Report. EHP-20048. 2023 Oct 24.

Apollo Uncertainty Considerations - Metabolic

- Metabolic rates on the Moon were less than predicted from ground testing
- Consumables usage was greater than predicted
  - Several cases of consumables at <10% capacity remaining at end of EVA
- EVAs were most often behind schedule and often extended beyond expected timeline
- Across Apollo 15-17:
  - 30 of 44 Stations visited as planned (2/3), remaining skipped
  - Only 2 Stations added

Miller, M. J., Claybrook, A., Greenlund, S., Marquez, J. J., & Feigh, K. M. (2017). Operational Assessment of Apollo Lunar Surface Extravehicular Activity. NASA Technical Reports, NASA/TP–20(July). Retrieved from https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170007261.pdf

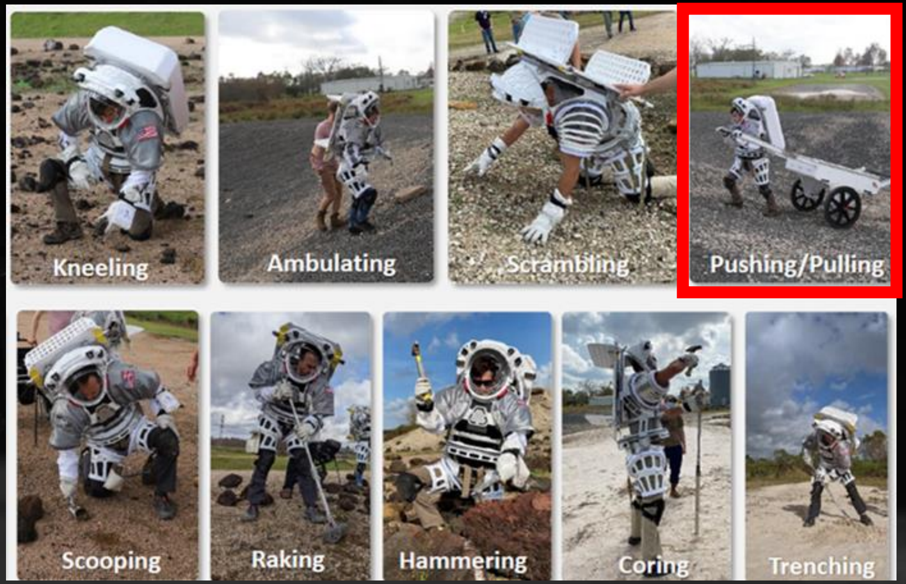
NASA Mission Operations Directorate (MOD) Summary of Apollo G mission lunar surface EMU post flight thermal analysis results, Table E1. Unpublished Internal Report. NASA Johnson Space Center, Houston.

Considerations for EVA Workload

- Physical workloads from field-based EVA training and testing have been observed to approach and briefly exceed 90+% age-predicted heart rate maxima, particularly during cart push/pull ops.
- Subjective responses indicated limited spare cognitive capacity via Bedford scale.

	Heart Rate (%Max HR)	Speed (kmh)	Distance (km)	Slope Along Track (deg)	Duration (hr)	% Time spent in HR zone (median [Max])	Bedford Rating
EVA1	Avg : 63% **EVA Max : 92%**	Avg = 1.1 Mx = 4.3	3.67	Avg = 5.1 Max = 16.2	3:27	Light Zone [Max]	3
	Avg : 64% **EVA Max: 95%**	Avg = 1.1 Mx = 4.9	3.86	Avg = 5 Max = 16.2		Light Zone [Max]	6
EVA2	Avg : 54% EVA Max : 82%	Avg = 1.2 Mx = 5.2	3.84	Avg = 3.6 Max = 18.1	3:06	Mod Zone [Max]	3
	Avg : 60% EVA Max: 83%	Avg = 1.2 Mx = 6.7	3.78	Avg = 3.5 Max = 18.1		Very Light [Hard]	6
EVA3	Avg: 60% EVA Max: 89%	Avg = 1 Mx = 5.4	4.91	Avg = 9.4 Max = 32.4	4:45	Very Light [Hard]	1
EVA4	Avg : 61% **EVA Max: 92%**	Avg = 1.3 Mx = 5.5	7.81	Avg = 4.2 Max = 22.6	5:56	Very Light [MAX]	1
	Avg : 56% EVA Max : 85%	Avg = 1.1 Mx = 5.8	4.97	Avg = 3.5 Max = 11.4		Very Light [HARD]	1

Very Light (50-59%)	Light (60-69%)	Moderate (70-79%)	HARD (80-89%)	MAX (90-100%)

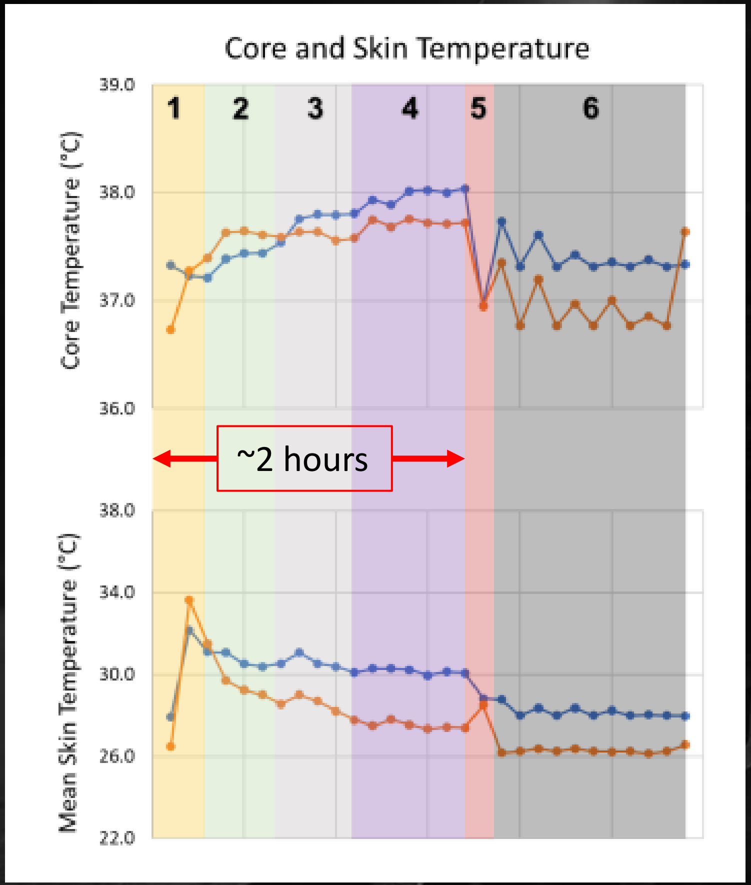


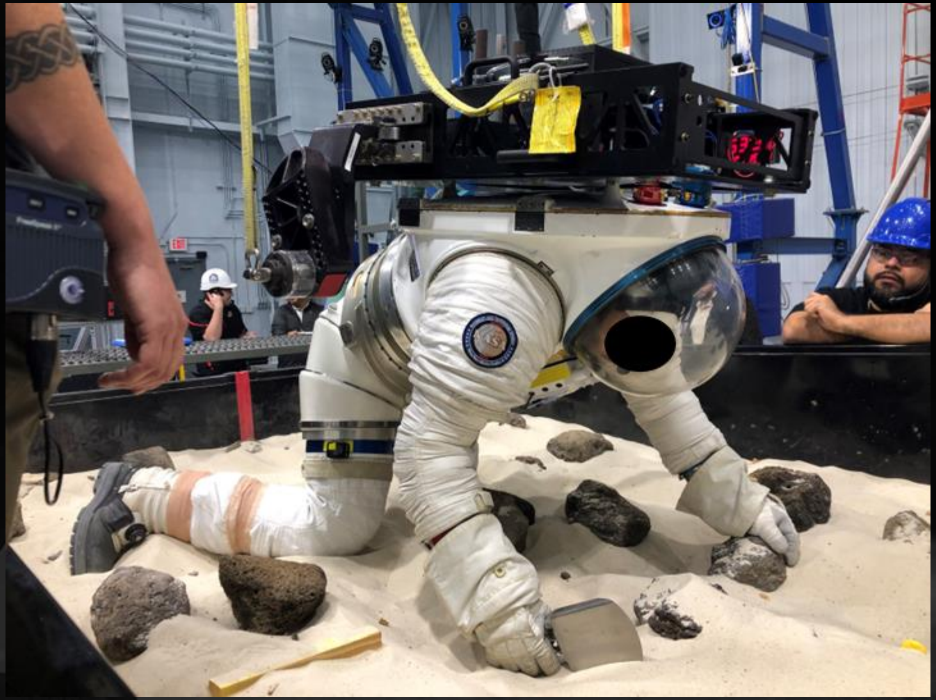
Coan DA, Miller MJ. Extravehicular Activity (EVA) & Human Surface Mobility (HSM) Program (EHP) Joint EVA & HSM Test Team (JETT) Field Test 3 (JETT3) Report. EHP-20021. 2023 Apr 18.

ARGOS Lunar - Thermal Burden

- Pilot data (n=2) reveal core body temperatures approaching 100° F in relatively short durations during nominal simulated tasks.

Task Block	EVA Task Circuit 1	Time (min)
1	Lander Platform	1
	1500m Traverse- Varied negative grades (−5%, −7%, and −10%)	≈30
2	Geology (Slope 0°)	15
	500m Traverse (30% grade)	≈10
3	Geology (Slope 10°)	15
	500m Traverse (20% Grade)	≈10
4	Object Relocation	15
	10 lb small and large	6
	20 lb small and large	6
	500m Traverse (10% Grade)	≈10
5	**BREAK**	30
	EVA Task Circuit 2	**Time (min)**
6	2000m Traverse- Varied grades (-10% to +30%)	≈45
	Geology Rake	5
	Geology Trench	5
	Geology Float Sample	5
	Geology Scoop	5
	Geology Sample Tagging	5
	Geology Drive Tube	10

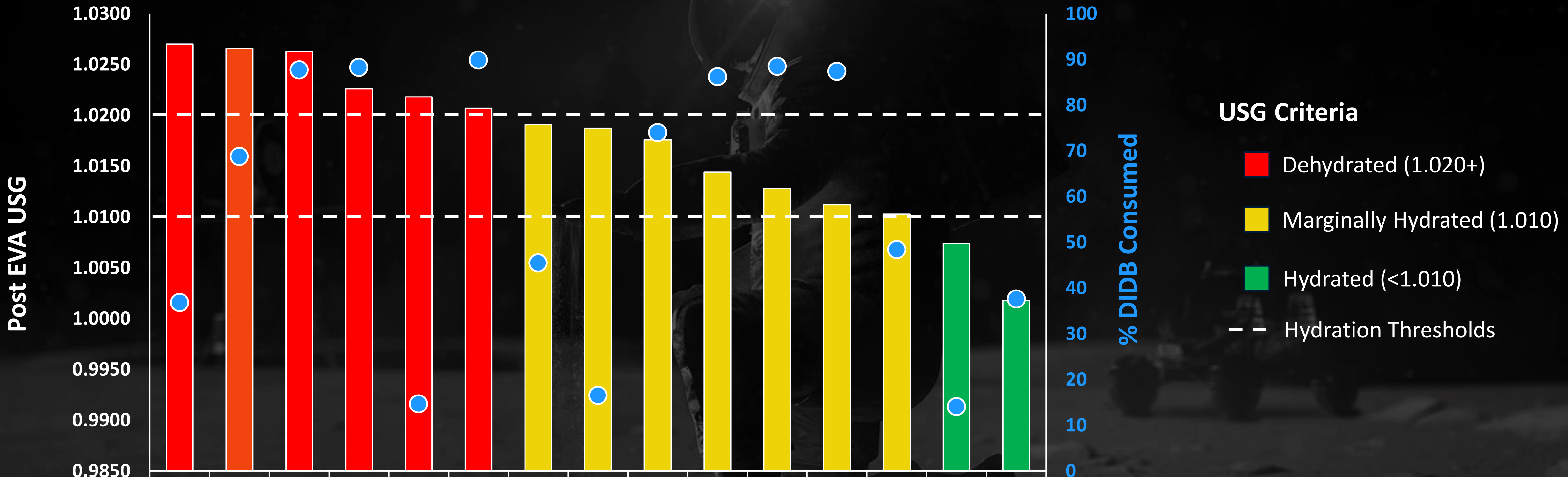




Hoffmann B, et al. "Human Thermal Analysis of Traverse and Geology Tasks During Simulated Lunar Extravehicular Activity." 2023 IEEE Aerospace Conference.

Considerations for In-suit Hydration

- Using urine specific gravity (USG) criteria, several crew finished simulated ISS EVAs in the NBL marginally hydrated or dehydrated despite adequate drink bag (DIDB) consumption.

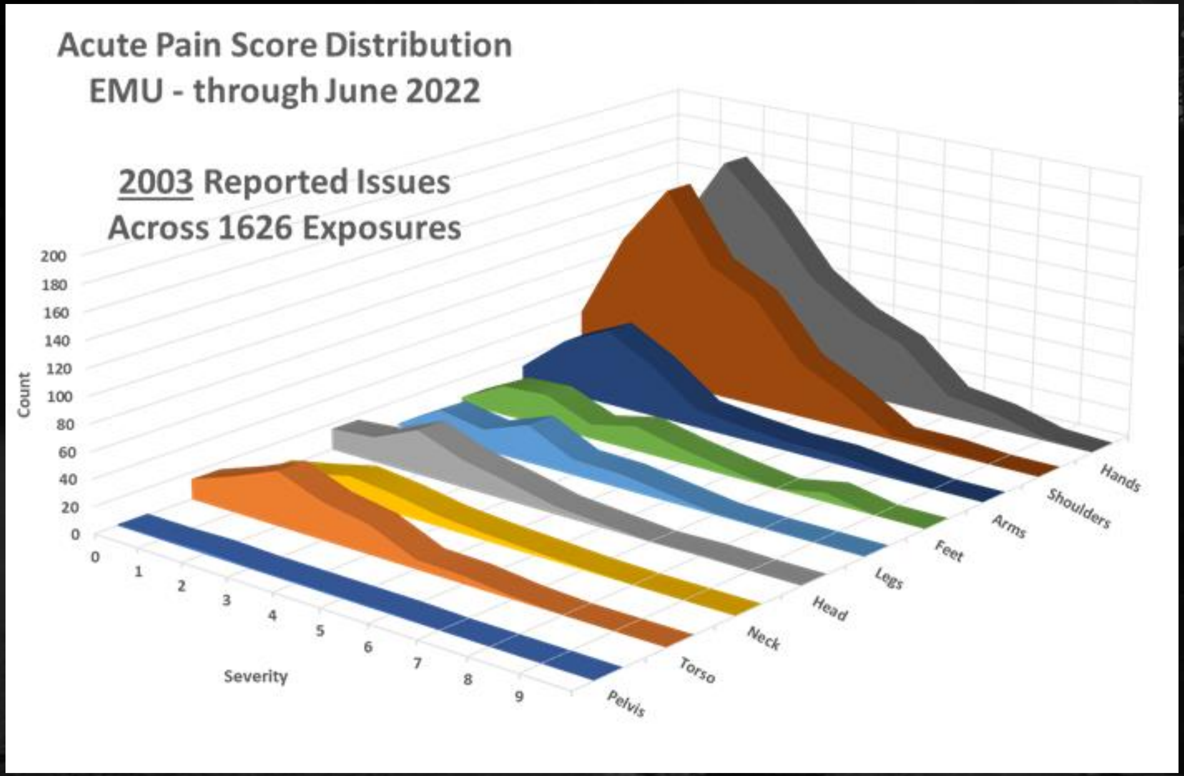


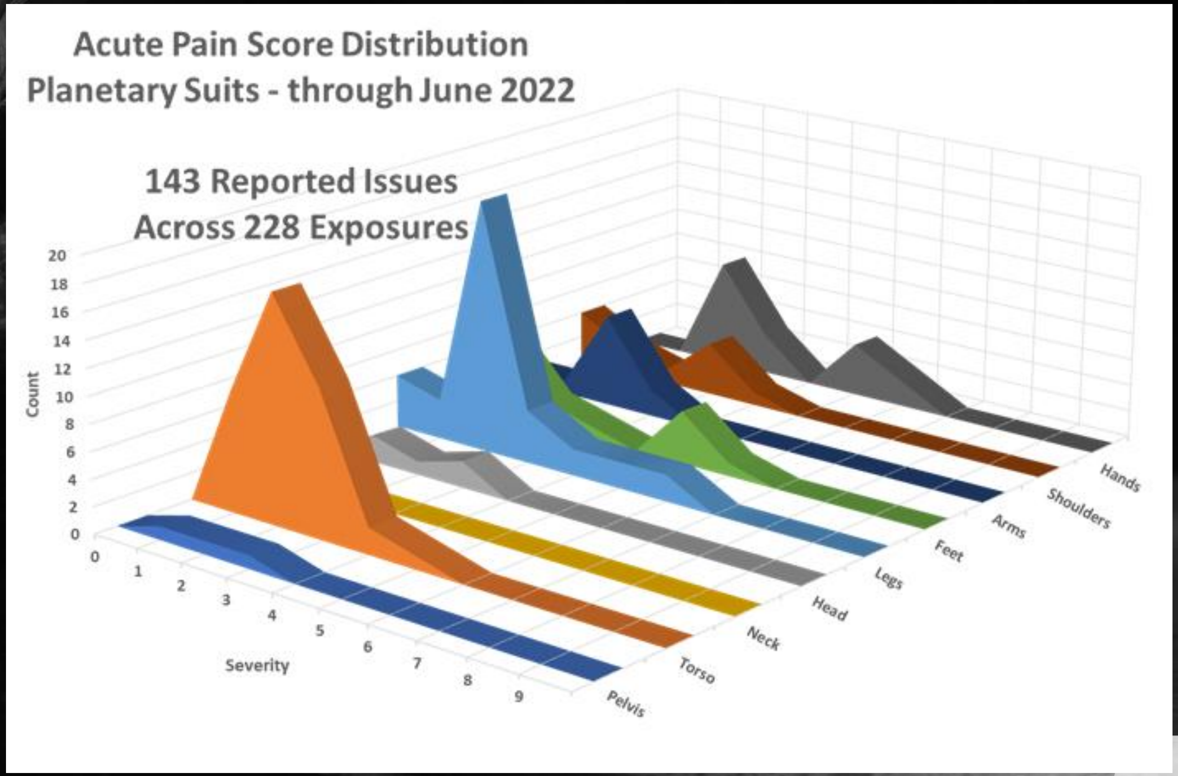
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
POST USG	1.027	1.027	1.026	1.023	1.022	1.021	1.019	1.019	1.018	1.014	1.013	1.011	1.01	1.007	1.002
%Change DIDB	36.80	68.76	87.67	88.22	14.62	89.81	45.47	16.49	73.98	86.19	88.44	87.37	48.38	14.05	37.60

Source: Hoffmann, Cooper, et al. Currently unpublished. 2024.

Considerations for Risk of Injury

- Preliminary data reveal significant changes in presentation of injuries between microgravity (left) and planetary (right) EVA testing and training events.

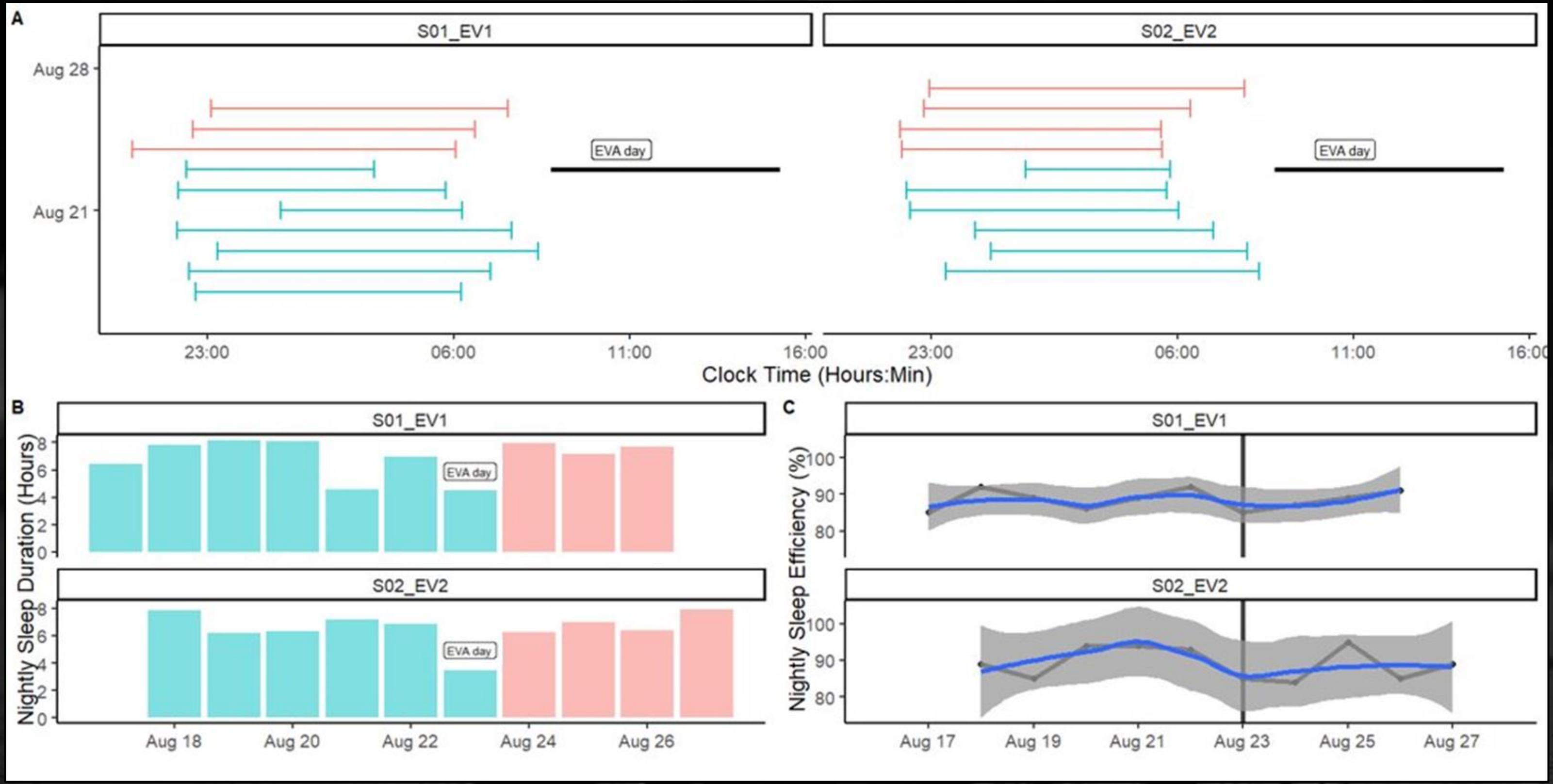




Source: Thompson, Reiber, Yates, et al. Currently unpublished. 2024.

ARGOS - Fatigue

- Pilot data (n=2) reveal deviations in participants sleep timing (Figure x. A bed and waketimes) and sleep duration (Figure x. B, hours of nightly sleep) from baseline for the night immediately prior to EVA runs
- Sleep Efficiency (Figure x. C) showed minimal deviation



Schlotman TE, et al. "A Preliminary Assessment of Cognition and Fatigue During Simulated Lunar Surface Extravehicular Activities." AsMA 93rd Annual Aerospace Medicine Scientific Meeting. 2023.

Future Work

- Understanding workloads, demands, and implications/decrements associated with operating exploration suits, tools, and procedures in high-fidelity analog environments.
    - Characterization of health and performance outcomes as a function of EVA duration and frequency.
    - Development of operational fitness for duty requirements and work-rest intervals during exploration operations.
    - Determine if/how deconditioning affects ability to perform early exploration tasks.

- Assess physical and cognitive performance when exposed to elevated CO_2 levels during EVA operations.
- Characterize and validate denitrogenation/prebreathe protocols and understand other risk factors that may influence development of decompression sickness.

Thank you!

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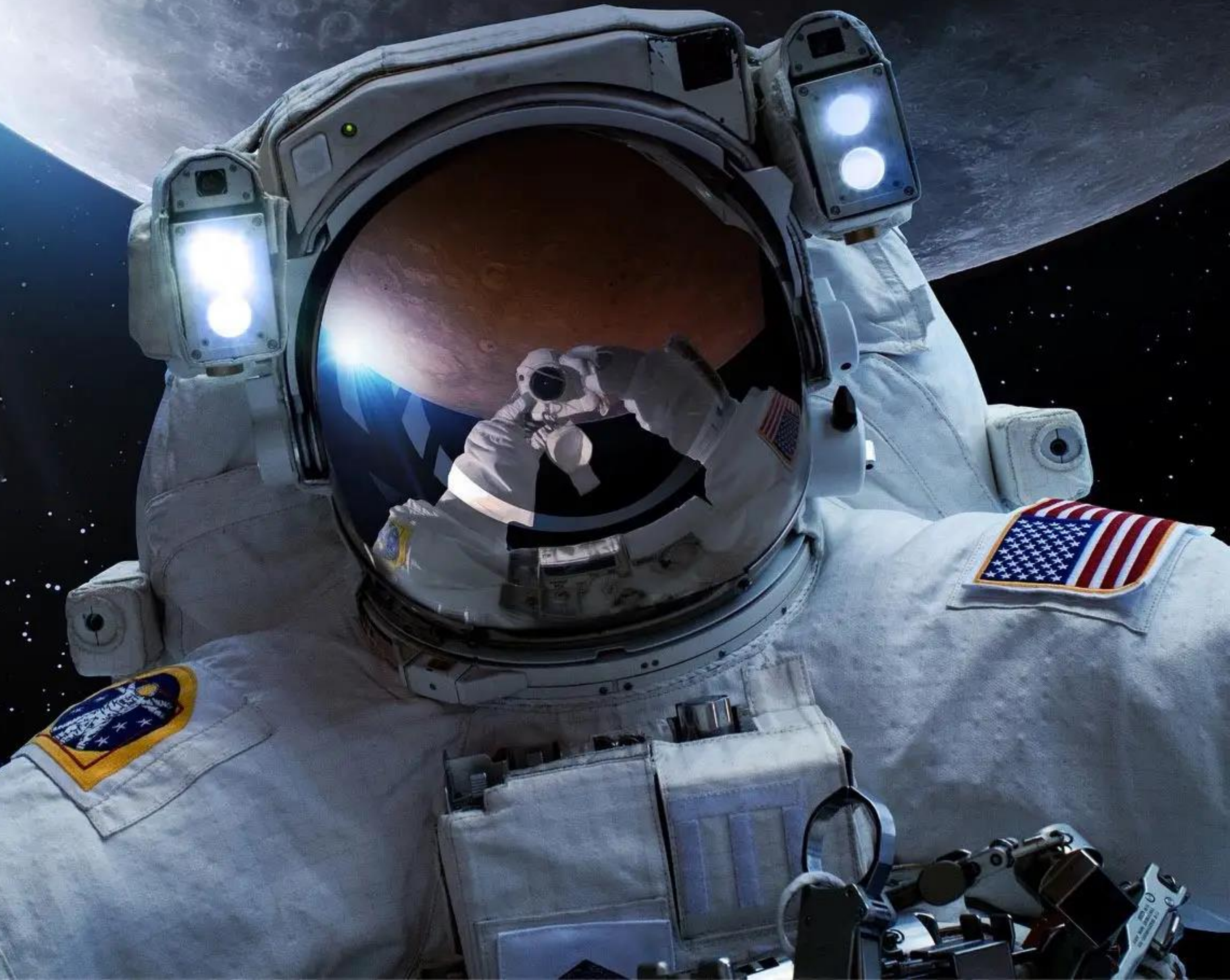
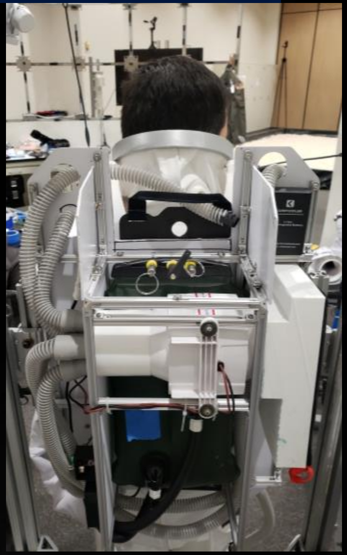
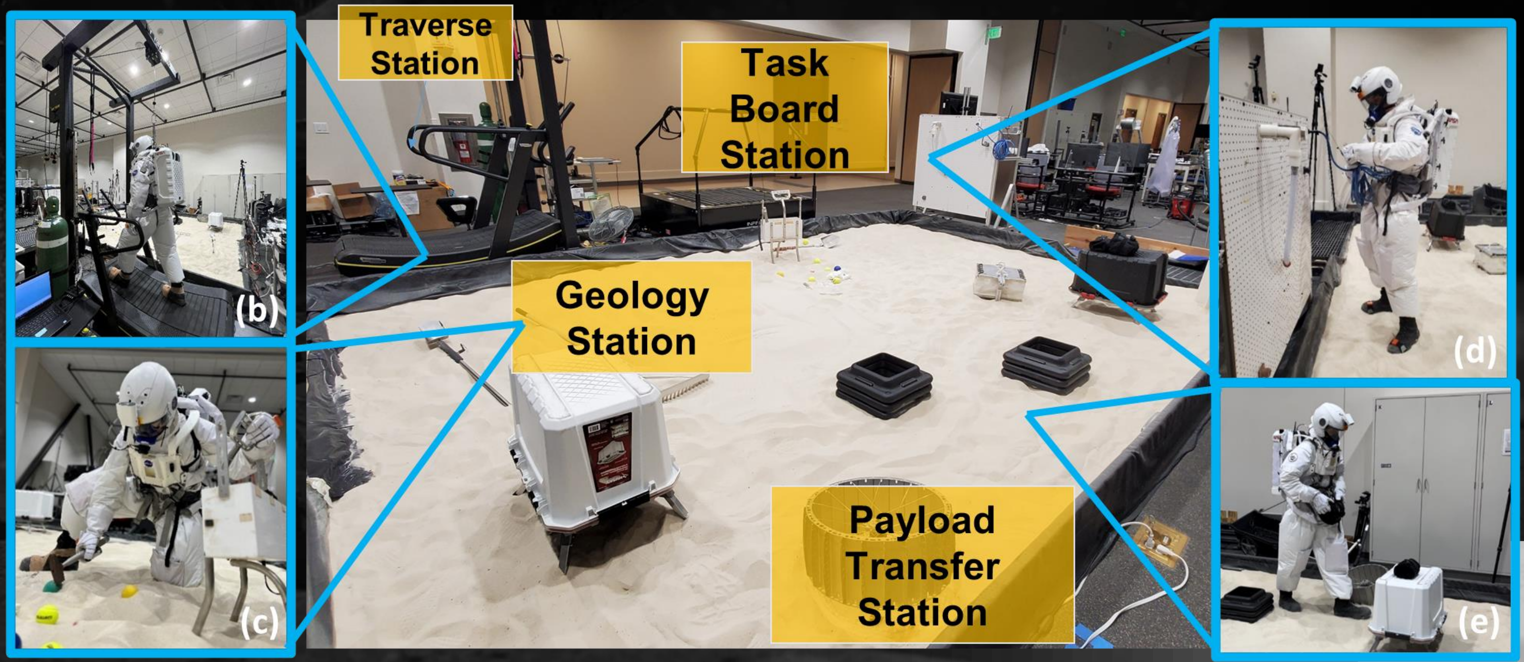


Hybrid Spacesuit Simulator (HS3)

- HS3 was developed as a research tool to add fidelity and realism by way of adjustable physical and cognitive workload
    - Subjectively has "Acceptable simulation quality"
        - No or minor limitations to data validity with feasibility of EVA immersion
    - Weight = ~40 lbs



- Current efforts seek to:
    - Assess, develop, and implement new potential subsystems
        - Capabilities to make outdoor-friendly
    - Characterize "baseline" configuration against shirtsleeve, VR/XR, and suited test environments



APACHE - Current Capabilities

- **15’ x 20’ footprint w/ Lunar regolith simulant**
- **Physical and cognitive workload simulators**
- **Options for long-distance ambulation**
  - Passive unidirectional treadmill
  - Omnidirectional treadmill
- **2-player operations**
- **Lunar environment (Shackleton crater) and [Martian environment](#) (Jezero crater)**
- **Physiologic sensors, computational models, and real-time informatics**
  - Metabolic rate / CO_2, Heart rate, Thermal, Cognitive/Fatigue
  - Seeking to add eye tracking, hand tracking, EEG/fNIRS, etc.
- **Embedded cognitive measures**
  - Psychomotor Vigilance Task (PVT)
  - Digital Symbol Substitution Task (DSST)
- **Realistic tools, assets, and end-to-end EVA simulation modules**
  - Aim to integrate omnidirectional treadmill and 6dof motion platform into VR/XR exploration environments
  - Aim to develop new EVA tools and procedures