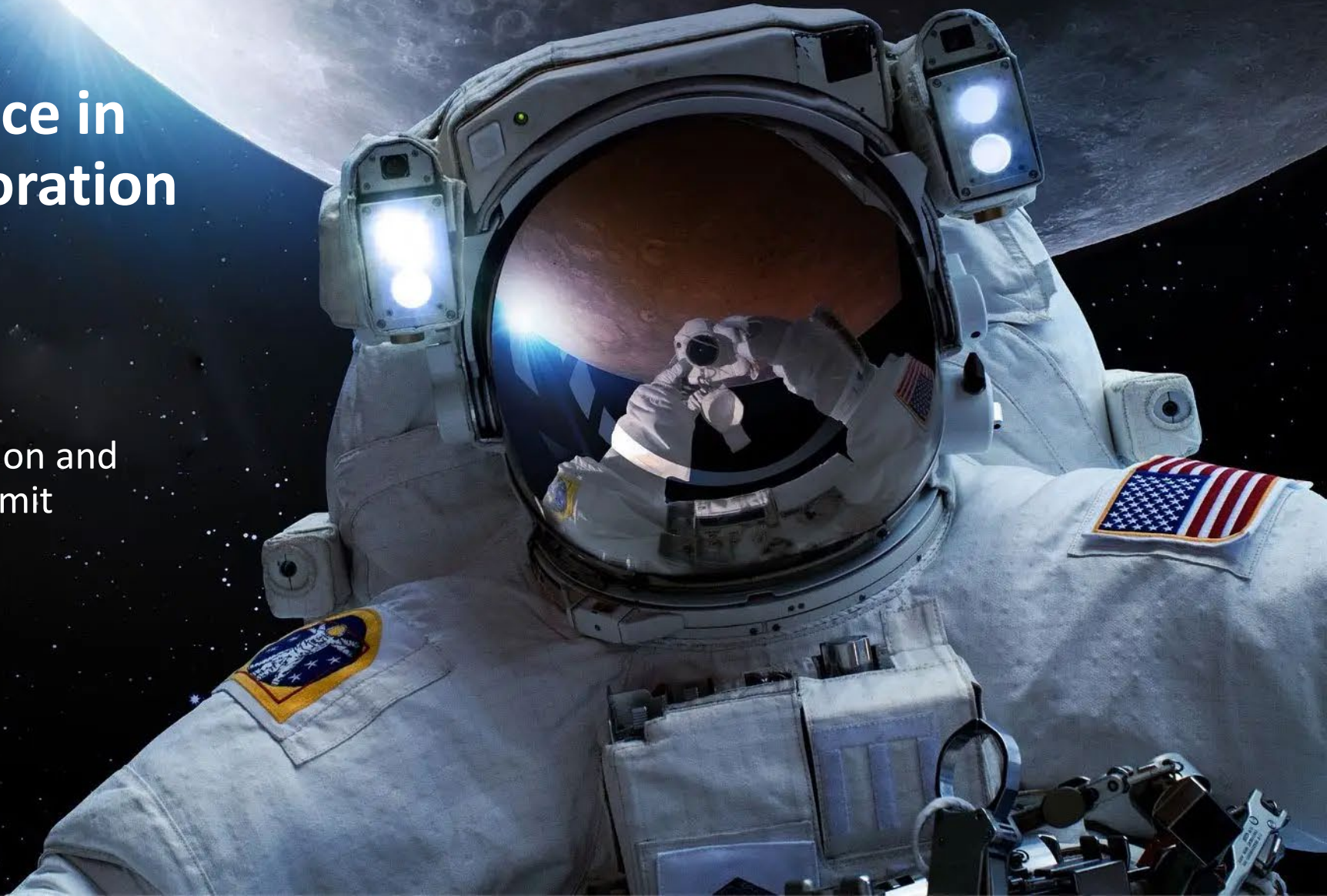


Human Performance in Spacesuits and Exploration Operations

Spaceflight Human Optimization and
Performance (SHOP) Summit

April 17-19, 2024

Patrick Estep



Background

- Artemis III will mark humanity's first return to the surface of the Moon since the Apollo Program, where astronauts will be sent to explore the region near the Lunar South Pole.
- The crewmembers who will have to perform extravehicular activities (EVAs) will be working in difficult conditions, in an unforgiving and unexplored environment, with new spacesuits and vehicle architectures.
- It is imperative that we understand and mitigate the multi-faceted human health and performance challenges and difficulties that may be experienced by crewmembers during these critical exploration missions – particularly those that may increase risk for injury or compromised performance.



EVA from the Human's Perspective

- EVA is ***NOT*** sufficient to serve as an exercise countermeasure.
 - But it is (*hard*) work that we need astronauts to perform, and it is fatiguing.
- Spacesuit is a personalized spacecraft / “mobile office”
 - Provides limited consumables to survive (e.g. O₂, pressure, H₂O/nutrition)
 - Manages/removes byproducts (e.g. CO₂, heat, humidity, waste)
 - Physical Implications
 - Suit is adjustable but doesn't fit individuals perfectly.
 - Must allow for mobility. Requires contact from human to manipulate.
 - Becomes more difficult at different suit pressures.
 - Functions/capabilities required to sustain and support life add mass + CG offset to the suit, which must be largely supported by the human.
 - All of this can be exacerbated by deconditioning.
 - Cognitive Demands
 - Autonomy and/or communications.
 - Comm delays or dropouts may present challenges.
 - Teamwork!
 - Visibility of environment and informatics/displays. Ability to survey, plan, interpret, and act.
 - Preparation for/cleanup after EVA puts additional burden on crew, even on non-EVA days.



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 ("Flexexecution")
Ops Support	MCC-centric Extensive personnel support	Crew-centric Delayed ground support

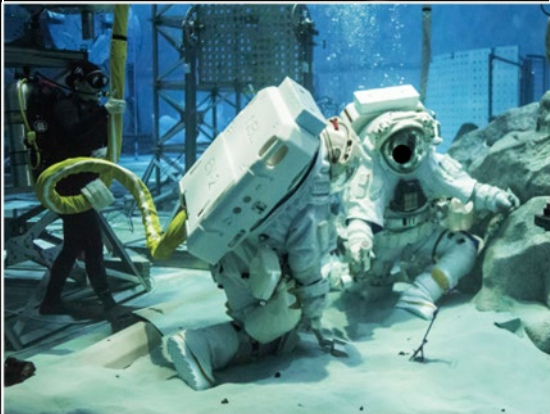
Future Exploration EVA will be quite different from ISS and Shuttle EVA, and even previous Apollo EVAs!

Key EVA Training, Simulation, and Test Environments



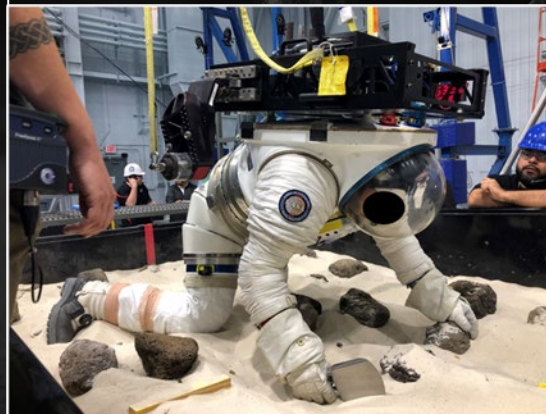
■ NBL

- 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

Recent Findings, Considerations and Future Work

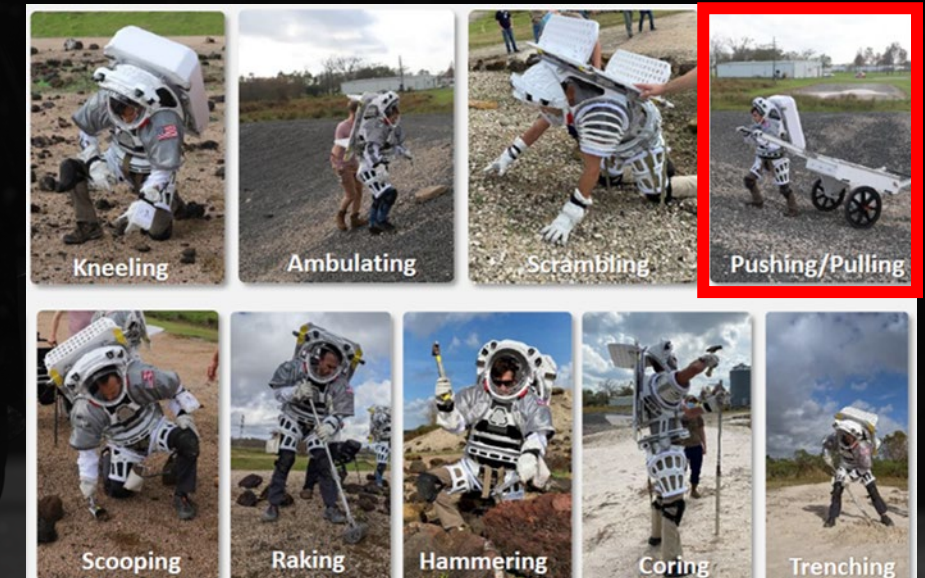
These efforts were primarily funded by the following organizations:

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

Considerations for EVA Workload

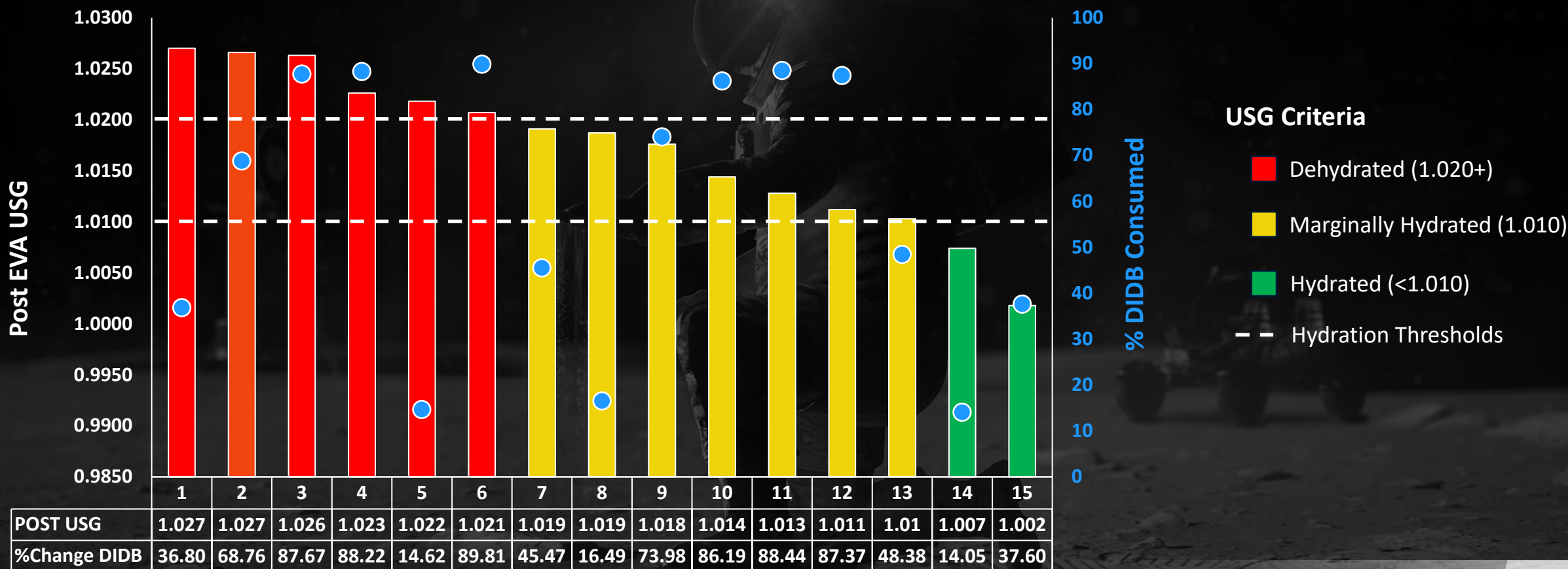
- Physical workloads from field-based EVA training and testing have been observed to approach and briefly exceed 90+% age-predicted heart rate maxima, particularly during cart push/pull ops.
- Subjective responses indicated limited spare cognitive capacity via Bedford scale.

	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%)	



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.



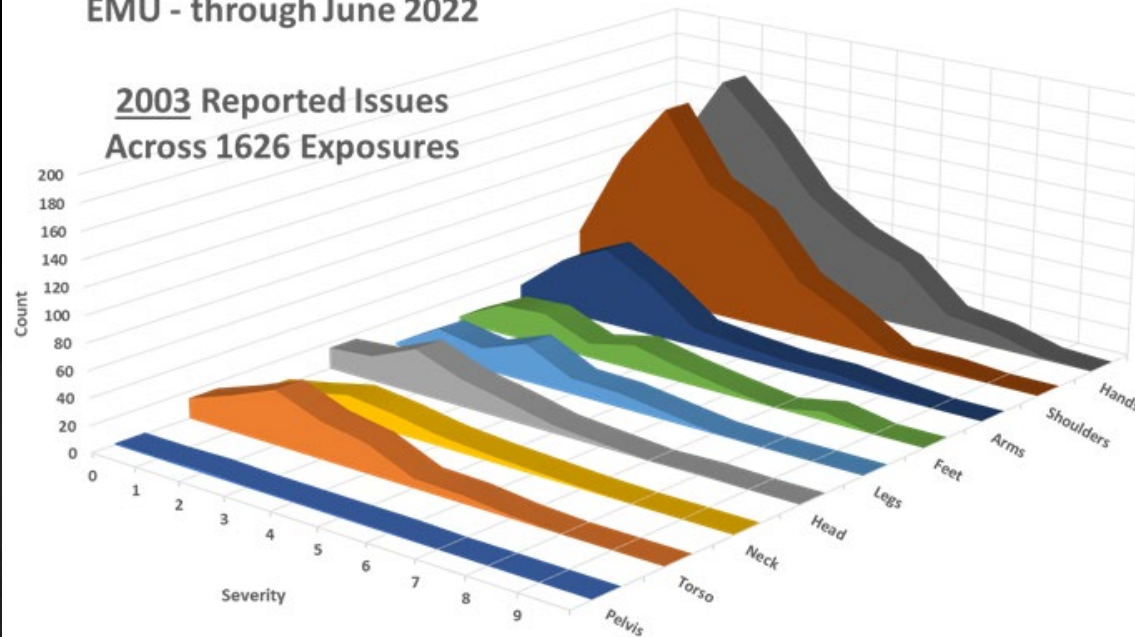
Considerations for Risk of Injury



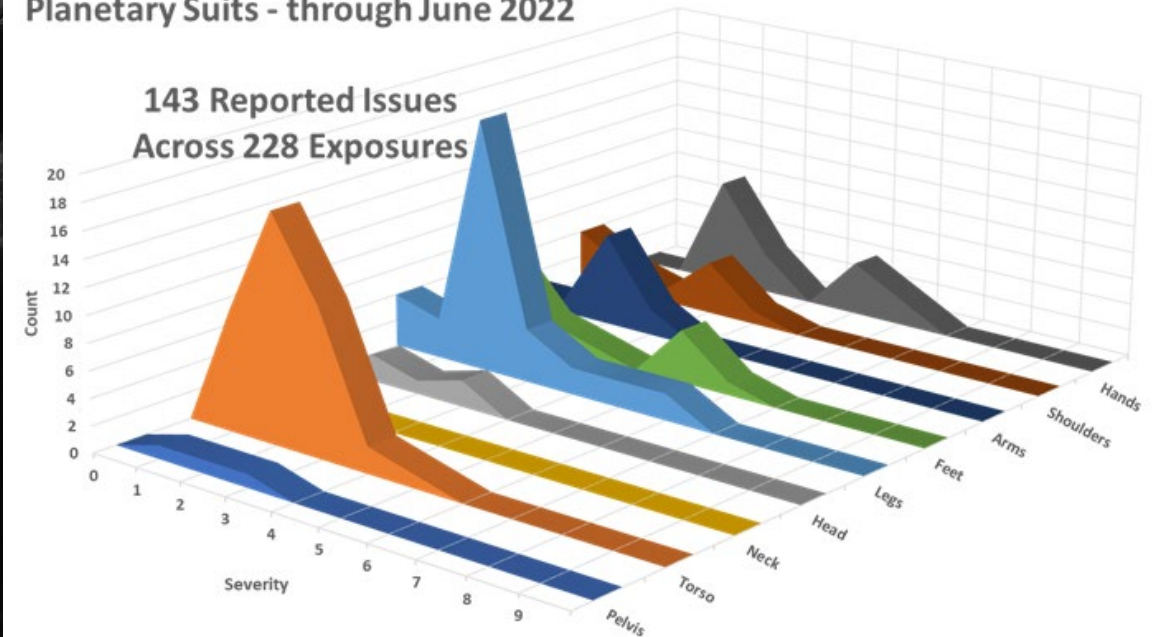
- Preliminary data reveal significant changes in presentation of injuries between microgravity (left) and planetary (right) EVA testing and training events.



Acute Pain Score Distribution
EMU - through June 2022



Acute Pain Score Distribution
Planetary Suits - through June 2022



Future Work

- Understanding workloads, demands, and implications/decrements associated with operating exploration suits, tools, and procedures in high-fidelity analog environments.
 - Robust, holistic, multidisciplinary characterization of health and performance outcomes as a function of EVA duration and frequency – especially fatigue and cognitive workload.
 - 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 CO₂ levels during EVA operations.
- In support of decompression sickness mitigation gaps, characterize capabilities and implications of operating spacesuits at elevated suit pressures.



Thank you!

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EVA ConOps for Surface Missions



- During surface missions, each crewmember may perform up to 24 hrs/week of EVA
 - Only twice has a crewmember performed 4 EVA/mission
 - Curbeam – day off between each EVA
 - Parazynski – day off between first 3, 3 days off between 3rd and 4th EVA
- For Artemis 3, each crewmember may conduct 4 EVAs in a 5-day time period & all crewmembers are required to perform EVA
 - Only **planned*** *back-to-back* EVAs were during Apollo with maximum 3 in 3 days
 - Shuttle had 3 unplanned back-to-back EVA series:
 - STS-37: unplanned EVA to free a stuck satellite antenna
 - *Crew recommended against back-to-back EVA for the future (1985)*
 - STS-51L: repairs slowed by malfunctioning robotic arm requiring 2nd EVA (1991)
 - STS-49: Details below (1992)

Apollo EVAs	Date
Apollo 15 -EVA 1	31-Jul-71
Apollo 15 - EVA 2	1-Aug-71
Apollo 15 - EVA 3	2-Aug-71
Apollo 16 -EVA 1	21-Apr-72
Apollo 16 - EVA 2	22-Apr-72
Apollo 16 - EVA 3	23-Apr-72
Apollo 17 -EVA 1	11-Dec-72
Apollo 17 - EVA 2	12-Dec-72
Apollo 17 - EVA 3	13-Dec-72

Mission EVA	Date	Purpose & Notes	Crewmember	EVA Time
STS-49 - EVA 1	5/10/1992	STS-49/Intelsat VI Capture & Repair	Thuot, Pierre - EV1 - EMU Hieb, Richard - EV2 - EMU	3:43:00
STS-49 - EVA 2	5/11/1992	Unplanned Repeat of EVA 1	Thuot, Pierre - EV1 - EMU Hieb, Richard - EV2 - EMU	5:30:00
STS-49 - EVA 3	5/13/1992	Unplanned Repeat of EVA 1&2 First & Only 3-Person EVA 2 nd Longest EVA	Thuot, Pierre - EV1 - EMU Hieb, Richard - EV2 - EMU Akers, Thomas - EV3 - EMU	8:29:00
STS-49 - EVA 4	5/14/1992	Assembly of Station by EVA Methods (ASEM) Cut from 2 to 1 EVA due to repeat EVA	Akers, Thomas - EV3 - EMU Thornton, Kathryn - EV4 - EMU	7:45:00

Uncertainty Considerations - Metabolic



- Metabolic rates during EVAs on the Moon were less than those predicted from ground testing
 - Metabolic rates have been observed approaching 60% of individual maximal capabilities for some tasks and motions during recent NBL Lunar simulations
- Apollo consumables usage was greater than predicted
 - Several cases of consumables at <10% capacity remaining at end of EVA
- Apollo 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)
 - 14 of 44 Stations skipped (1/3)
 - 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/2017/0007261.pdf>

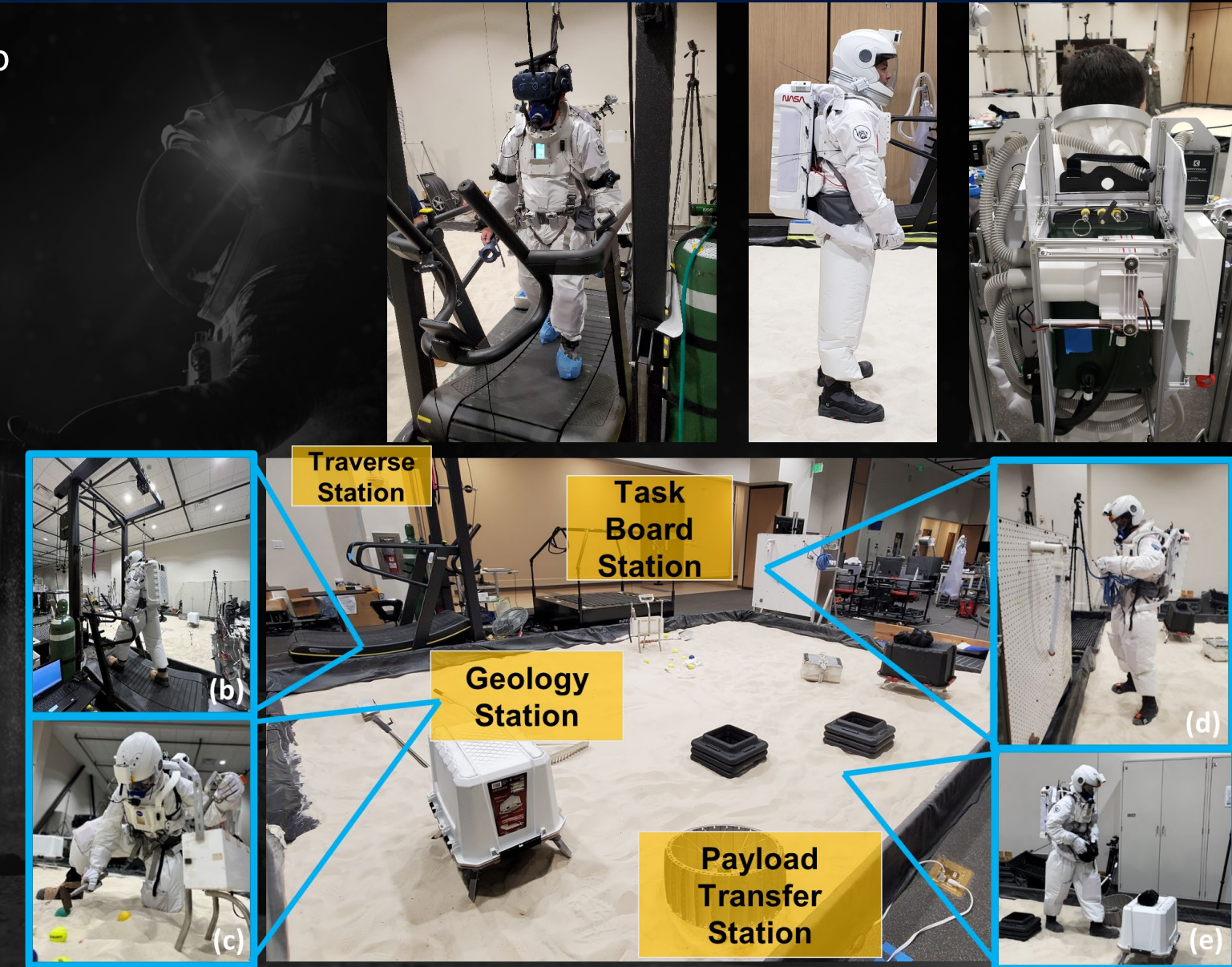
NASA Mission Operations Directorate (MOD) Summary of Apollo G mission lunar surface EMU post flight thermal analysis results, Table E1. Unpublished Internal Report. NASA Johnson Space Center, Houston.

EHP-20048.

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 / CO₂, 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

