



# ENSURING SAFE DECISION-MAKING ON THE MOON AND MARS: COGNITIVE PERFORMANCE ASSESSMENT FOR EXPLORATION CLASS MISSION EVA

Steven R. Anderson, PhD<sup>1</sup>

Mercedes Jorge, MS<sup>1</sup>

Suzanne T. Bell, PhD<sup>2</sup>

<sup>1</sup>KBR, Behavioral Health & Performance Laboratory

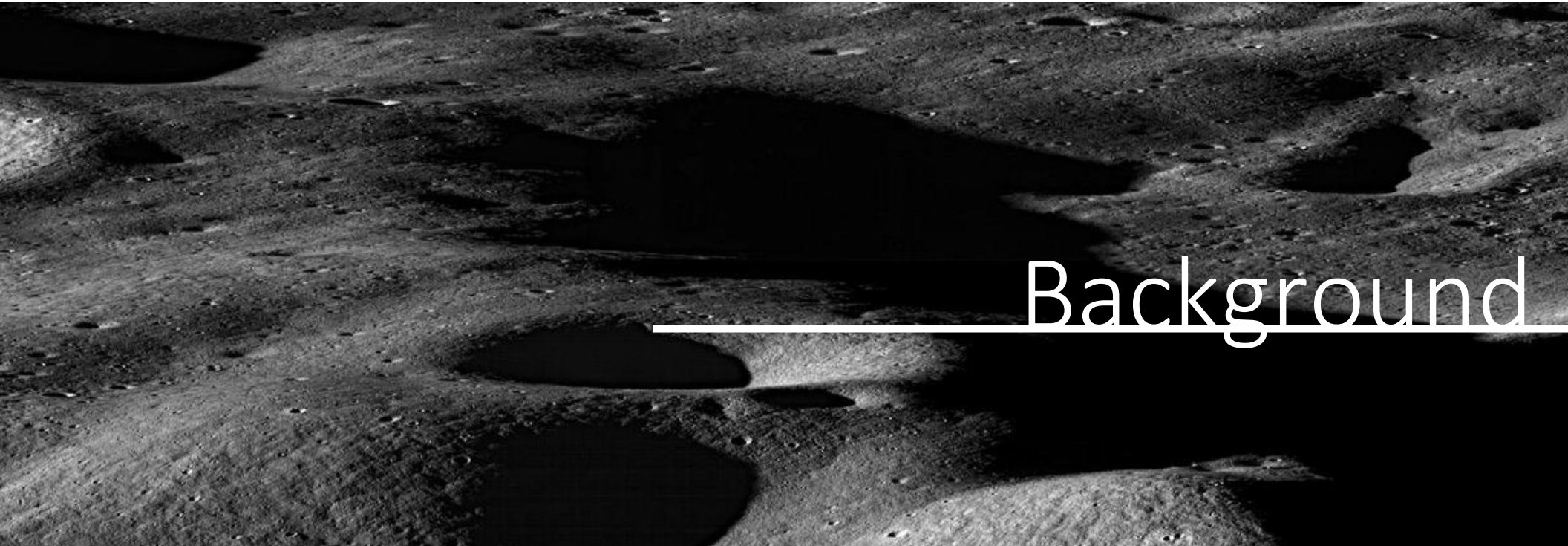
<sup>2</sup>NASA, Behavioral Health & Performance Laboratory

Image Credit: NASA



# Outline

- Background
- Methods
- Results
- Conclusion
- Future Directions



Background

# Why is cognitive performance important for EVA?

EVA Readiness

Pre-EVA

EVA Task Performance

During EVA

EVA Impacts

Post-EVA

Image Credit: NASA

Radiation

Circadian  
Misalignment

Isolation

EVA Readiness

EVA Task Performance

EVA Impacts

Pre-EVA

During EVA

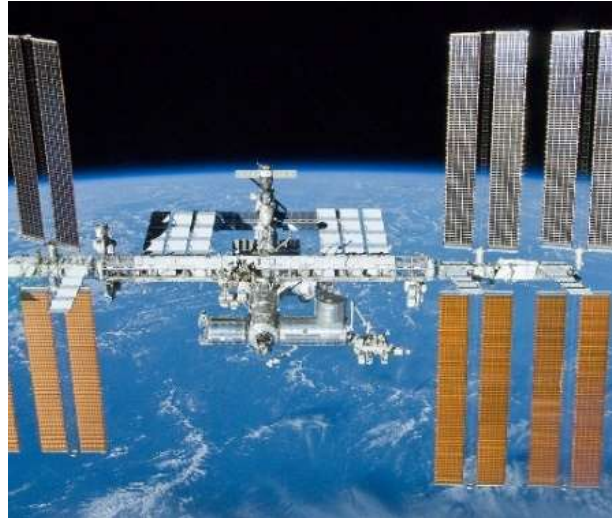
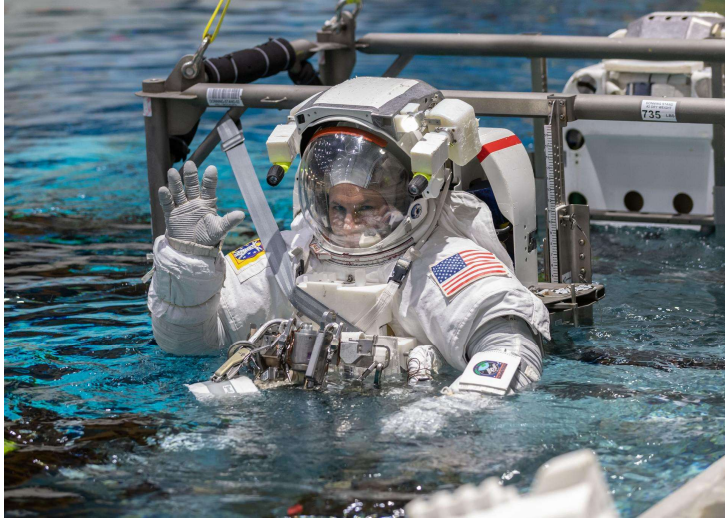
Post-EVA

Altered  
Gravity

Communication  
Delay

Fluid  
Shifts

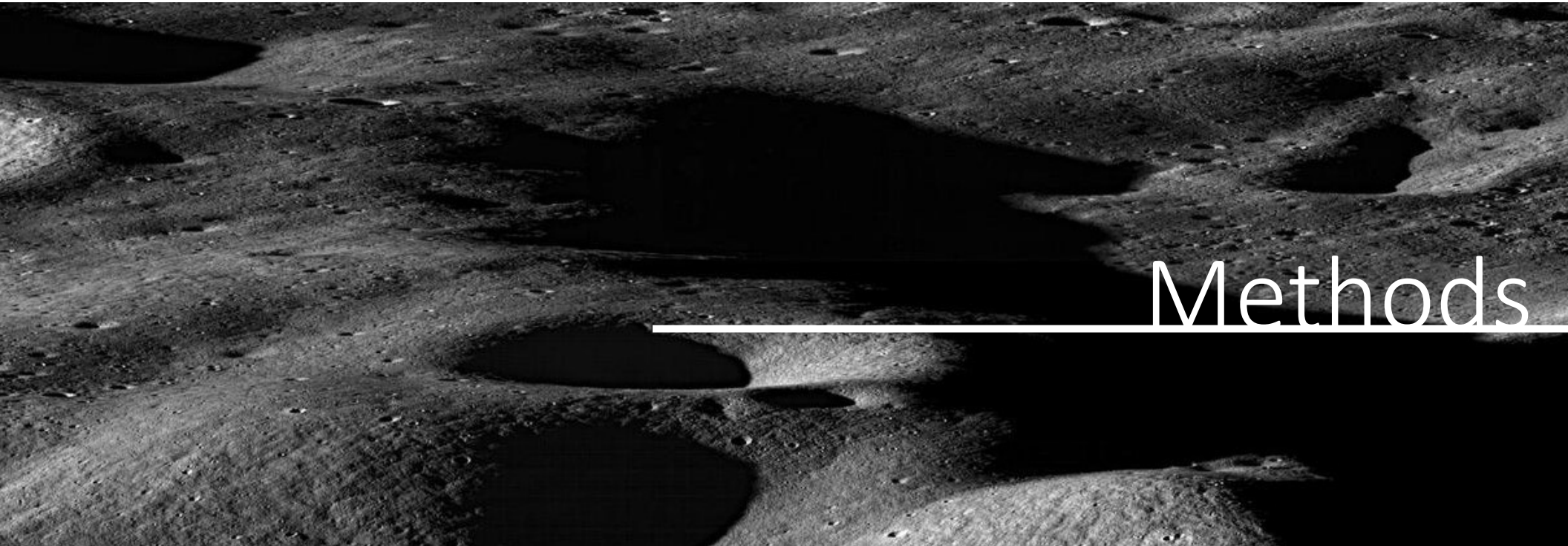
Image Credit: NASA



## NASA Behavioral Health & Performance (BHP) Laboratory

- Laboratory Lead: Suzanne Bell, PhD
- BHP MCO Cognitive Performance EVA Research
  - Lead Scientist: Steven Anderson, PhD
  - Lead Research Coordinator: Mercedes Jorge, MS
- Lab conducts research to better understand the psychological and behavioral responses to spaceflight using spaceflight and spaceflight analog environments
- Lab expertise in industrial/organizational, cognitive neuroscience, and health psychology

Image Credit: NASA

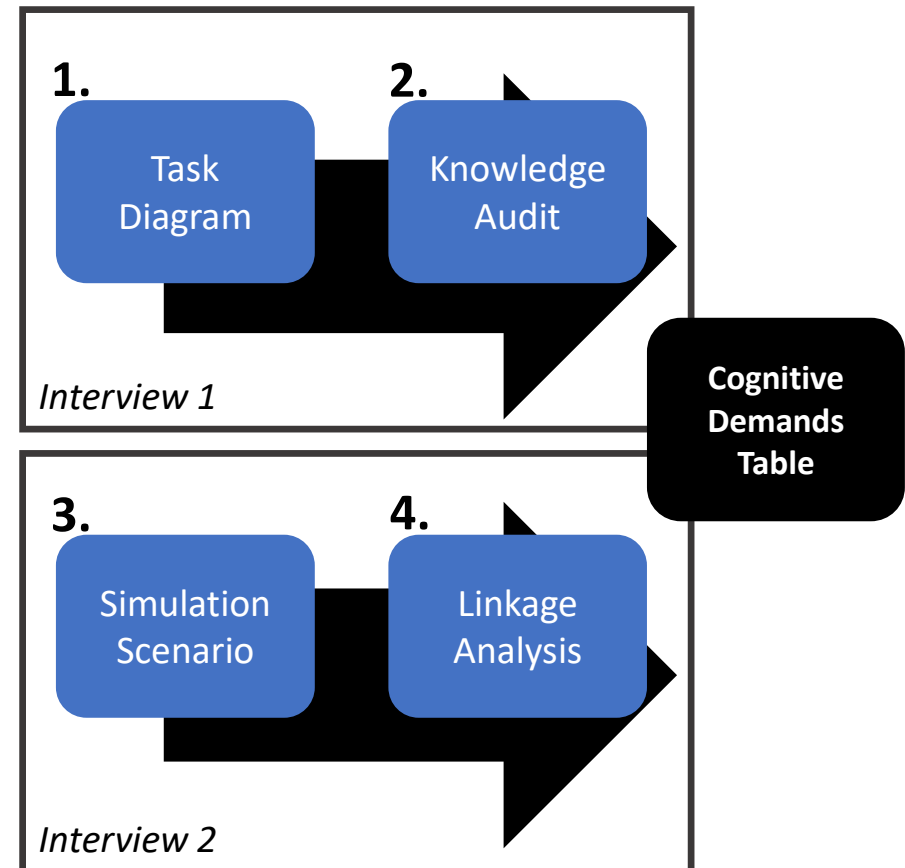


# Methods

# Cognitive Task Analysis (CTA)



- **Background:** CTA is a set of methods for identifying the cognitive skills, or mental demands, needed to perform a task proficiently. CTA was used to identify cognitive capabilities for successful EVA task performance
- **Method:** A modified version of Militello & Hutton's (1998) Applied Cognitive Task Analysis (ACTA) method was used
- **Procedure:** Two 60-minute interviews with astronauts and subject matter experts in EVA operations and research
- **Interviewer:** PhD-level scientist with expertise in health psychology and cognitive neuroscience
- **Notetaker:** Master's-level research coordinator with expertise in industrial/organizational psychology

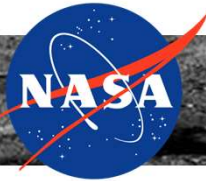


# EVA Tasks and Subtasks



Tasks	Subtasks
<b>EVA Prep/Post Ops</b>	Don/doff suit
	Open/close hatch
<b>Inspection of Surroundings</b>	Photography
	Inspection
<b>Sample Identification</b>	Place Sample Marker
<b>Sample Collection: Rock</b>	Float Sample
	Chip Sample
	Rake Sample
<b>Sample Collection: Regolith</b>	Bulk Scoop Sample
	Core Sample (single)
	Core Sample (double)
	Surface Collection Sample
	Trench Sample

# EVA Tasks and Subtasks

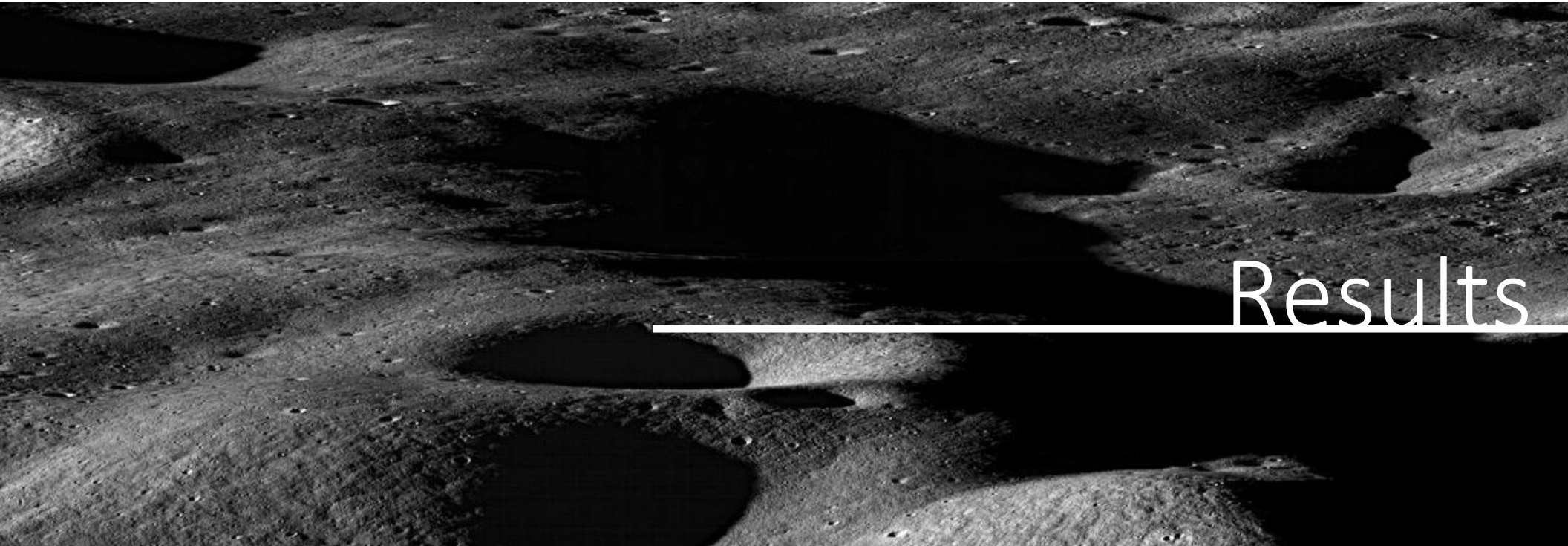


Tasks	Subtasks
<b>Surface Mobility</b>	EVA adaptation (Ambulation)
	EVA adaption (Postural Change-Kneeling)
	Descend/Ascend Ladder
	Descend/Ascend Steps
<b>Maintenance Tasks</b>	Mating/Demating Connectors
	Removing/Installing (Fasteners)
	Removing/Installing (Hardware)
	Cable Management (Burying)
	Cable Management (Routing)
	Dust Mitigation (Clean equipment)
<b>Payload Operations</b>	Transport Payload (without cart)
	Transport Payload (with cart)
	Deploy/Retrieve Payload

# EVA Tasks and Subtasks



Tasks	Subtasks
<b>Public Affairs Operations</b>	Flag Deployment
	Plaque Deployment
<b>Traverse</b>	Traverse (without cart)
<b>Worksite setup/cleanup</b>	Tool Sample Retrieval
	Sample Retrieval
	Storage



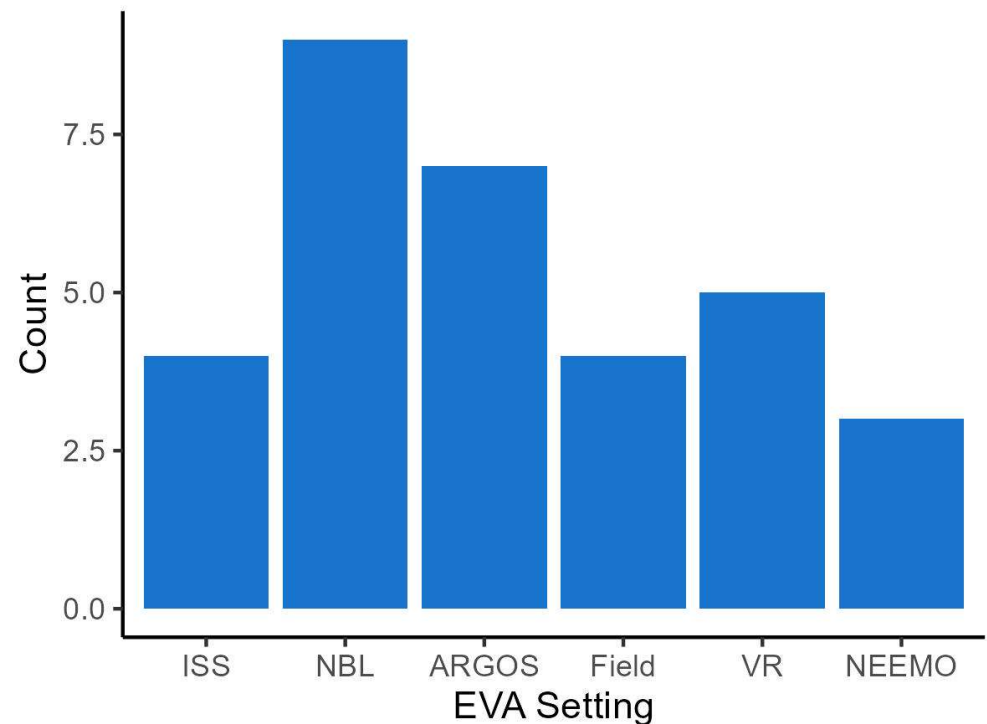
Results

# Interviewees



- **Interviewees:** 15 astronauts and subject matter experts in EVA operations and research
  - 6 experts in EVA Research
  - 5 experts in EVA Operations
  - 4 NASA/ESA astronauts
- **Experience:** Average of 7.5 years (range = 2–19 years, SD = 5.32) of EVA experience across multiple spaceflight and analog settings
  - Astronauts had a total of 71 hours 33 minutes of EVA time on ISS

EVA Experience by Setting

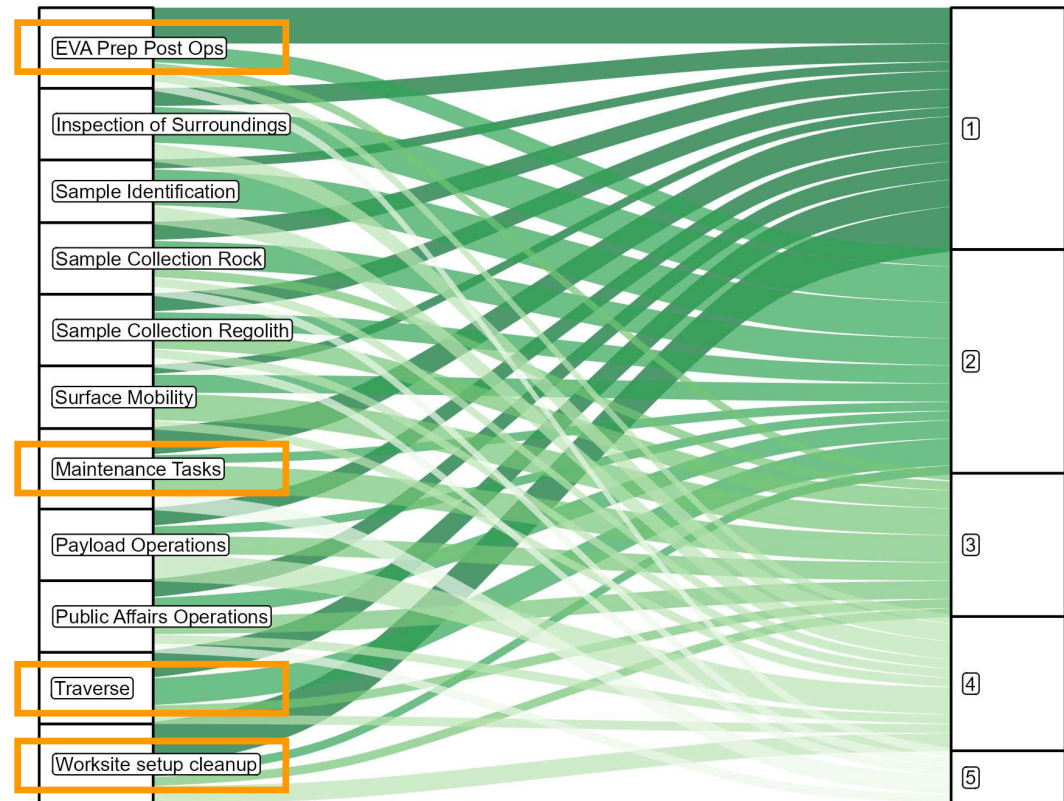


# Expertise Rankings



- Experts ranked how much expertise they had for the 11 EVA Tasks (1 = Most Expertise)
- Experts could designate multiple EVA Tasks with the same ranking
- Expertise was distributed across multiple EVA tasks
- EVA tasks that were most often ranked as highest (#1) in expertise were:  
**Worksite Setup/Cleanup** (5 experts),  
**EVA Prep/Post Ops** (4 experts),  
**Maintenance Tasks** (3 experts), and  
**Traverse** (3 experts)

## EVA Tasks Ranked by Expertise

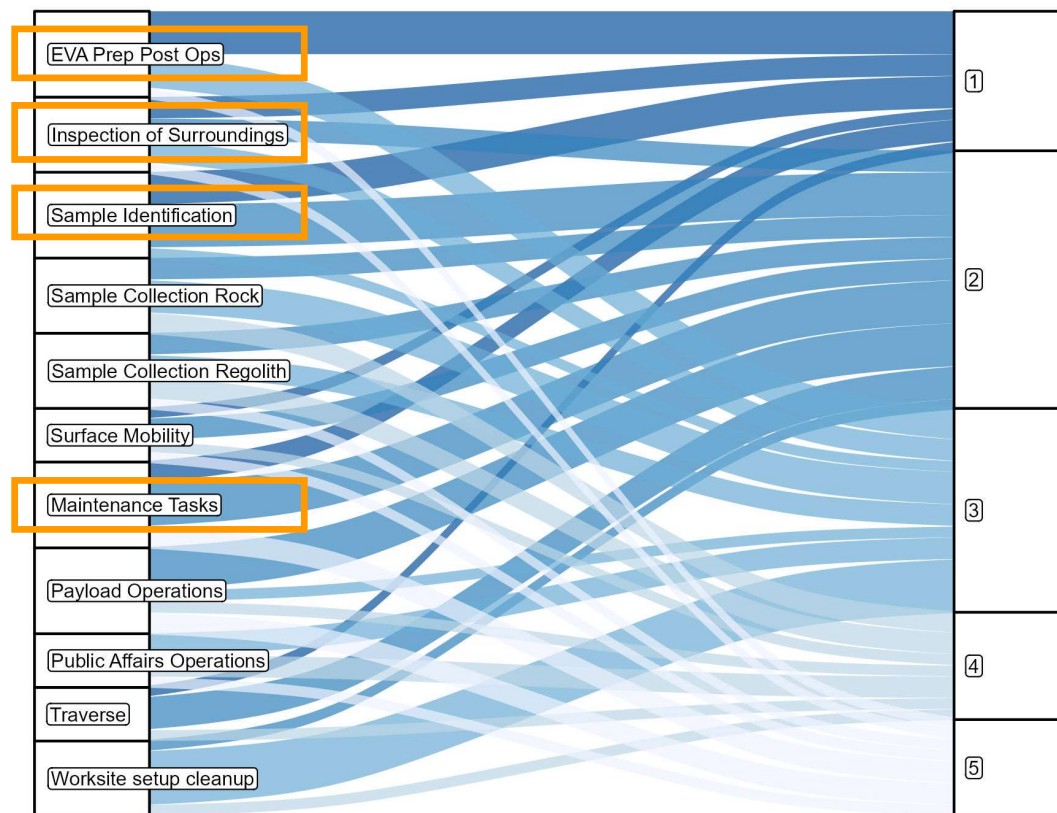


# Cognitive Demand Rankings



- Experts ranked the level of cognitive demand for the 11 EVA Tasks (1 = Most Cognitive Demand)
- Experts could designate multiple EVA Tasks with the same ranking
- Cognitive demand was distributed across multiple EVA tasks
- EVA tasks that were most often ranked as highest (#1) in cognitive demand were: **EVA Prep/Post Ops** (4 experts), **Sample Identification** (3 experts), **Inspection of Surroundings** (2 experts), and **Maintenance Tasks** (2 experts)

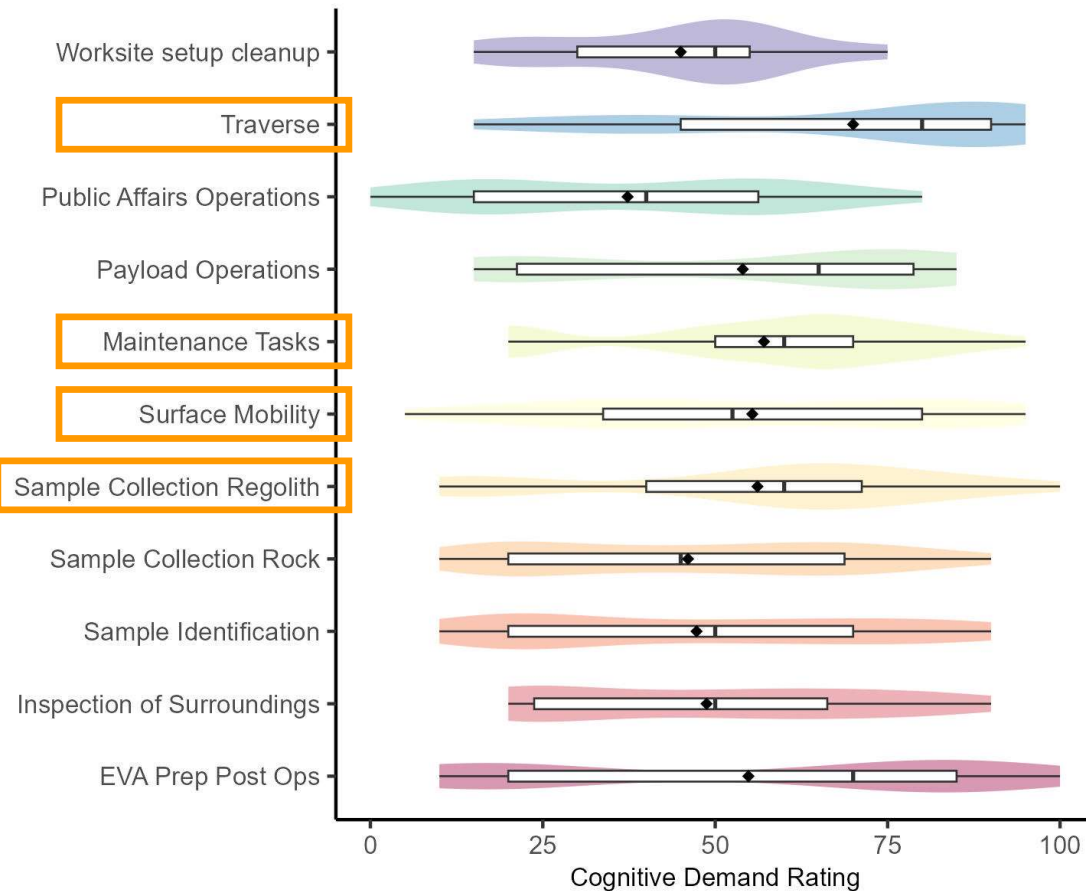
## EVA Tasks Ranked by Cognitive Demand



# EVA Task Cognitive Demand Ratings



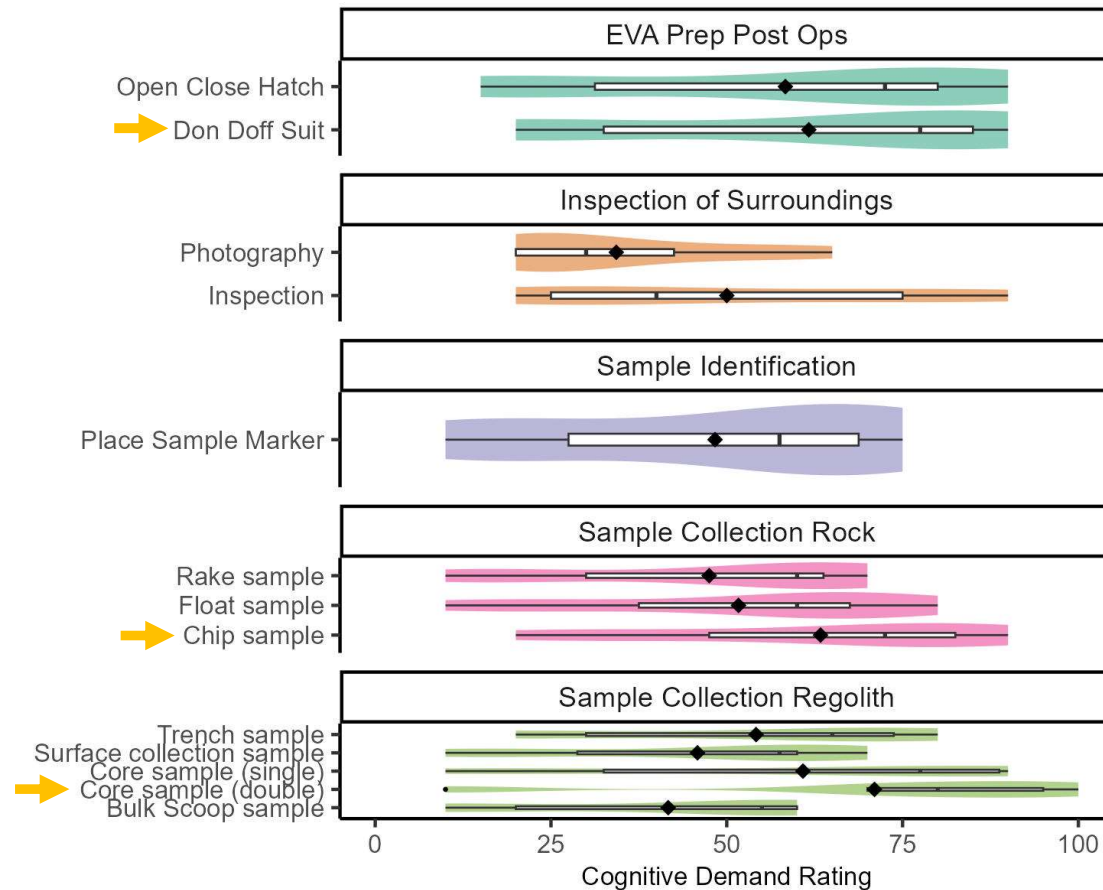
- Experts indicated through ratings (0 = Low to 100 = High) that the following EVA Tasks were highest in cognitive demand: **Traverse** (M = 70.0, SD = 27.0), **Maintenance Tasks** (M = 57.1, SD = 22.0), **Sample Collection: Regolith** (M = 56.1, SD = 26.3), **Surface Mobility** (M = 55.4, SD = 27.4), and **EVA Prep/Post Ops** (M = 54.8, SD = 33.8)
- EVA Tasks were overall rated as cognitively demanding (M = 51.7, SD = 26.1)



# EVA Subtask Cognitive Demand Ratings



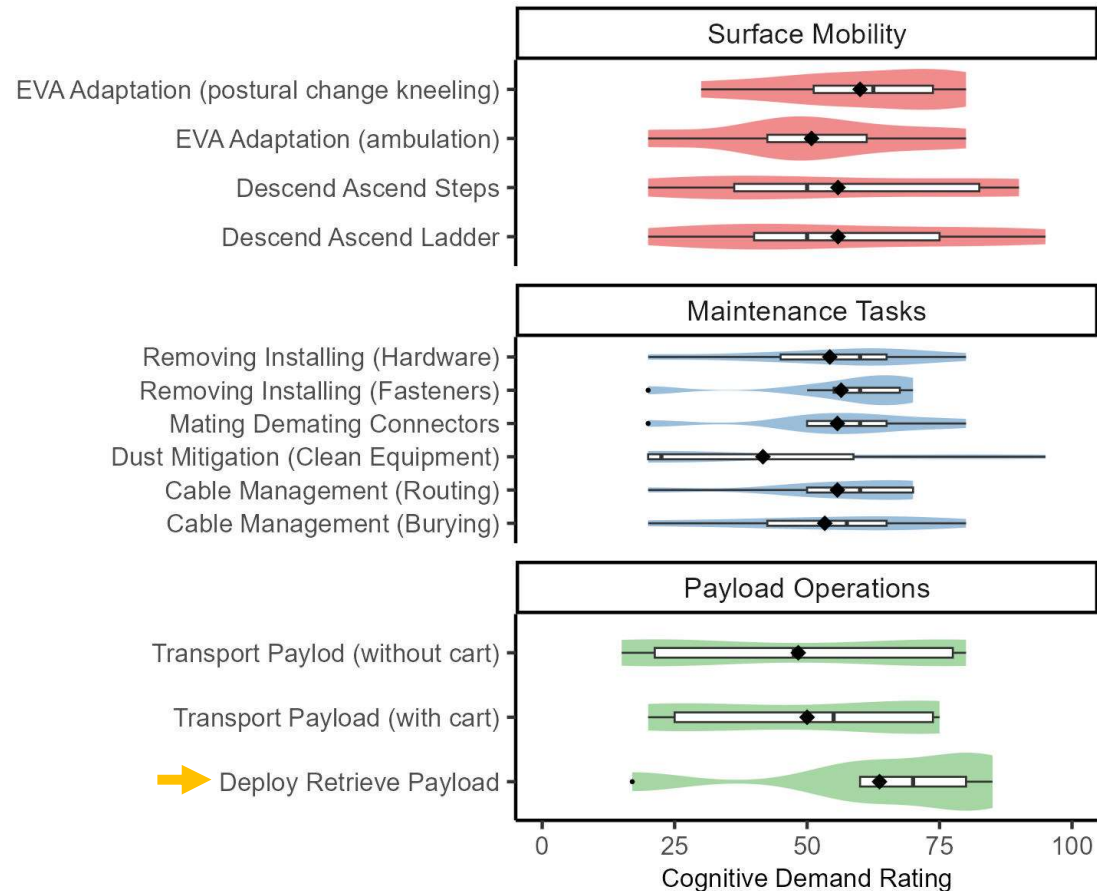
- There was considerable variability in ratings for EVA subtasks
- Experts rated the following subtasks as having the highest cognitive demand: **Core sample (double)** (M = 71.0, SD = 36.1), **Deploy/Retrieve Payload** (M = 73, SD = 12), **Chip Sample** (M = 63.3, SD = 27.5), and **Don/Doff Suit** (M = 61.7, SD = 33.0)



# EVA Subtask Cognitive Demand Ratings



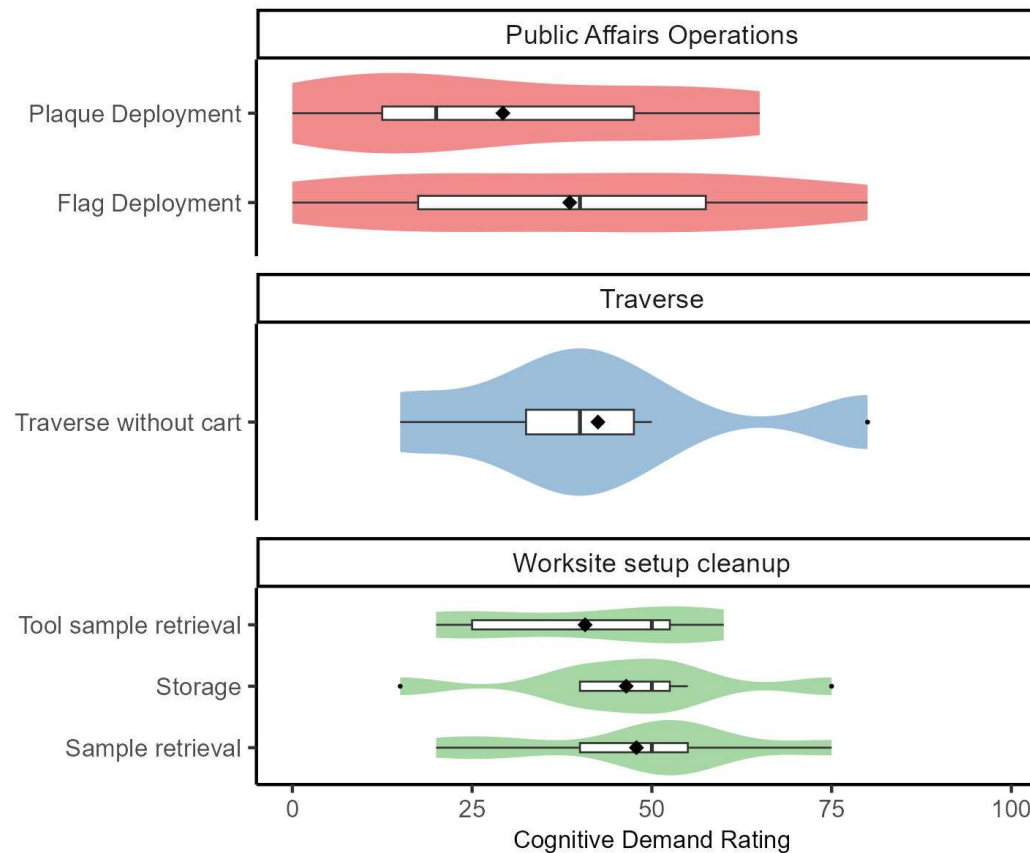
- There was considerable variability in ratings for EVA subtasks
- Experts rated the following subtasks as having the highest cognitive demand: **Core sample (double)** (M = 71.0, SD = 36.1), **Deploy/Retrieve Payload** (M = 73, SD = 12), **Chip Sample** (M = 63.3, SD = 27.5), and **Don/Dooff Suit** (M = 61.7, SD = 33.0)



# EVA Subtask Cognitive Demand Ratings



- There was considerable variability in ratings for EVA subtasks
- Experts rated the following subtasks as having the highest cognitive demand:  
**Core sample (double)** (M = 71.0, SD = 36.1),  
**Deploy/Retrieve Payload** (M = 73, SD = 12), **Chip Sample** (M = 63.3, SD = 27.5), and **Don/Dooff Suit** (M = 61.7, SD = 33.0)



# Knowledge Audit



- **Purpose:** The knowledge audit employs a set of probes designed to describe types of domain knowledge or skill and elicit appropriate examples
- Knowledge Audit focused on the EVA Tasks that the interviewee had the most expertise in (based on expertise rankings)
- Example probe categories included Big Picture: *Can you give me an example of what is important about the Big Picture for inspecting your surroundings?*

## Knowledge Probe

- *Past and Future*
- *Big Picture*
- *Noticing*
- *Job Smarts*
- *Opportunities/Improvising*
- *Self-Monitoring*
- *Anomalies/Off-Nominal Situations*
- *Equipment/Spacesuit Difficulties*

Skills  
Required

Specific  
Events

Cues &  
Strategies

Why Difficult

# Knowledge Audit



EVA Prep/Post Ops		
<i>Aspects of Expertise</i>	<i>Cues and Strategies</i>	<i>Why difficult?</i>
<ul style="list-style-type: none"> <li>• <b><u>Rely on extensive ground training</u></b> to perform EVA prep/post ops effectively and safely</li> <li>• <b><u>Ensure proper communication</u></b> during spacesuit donning, airlock operations, and tool preparation</li> <li>• <b><u>Safety is a tool to accomplish the task at hand</u></b>; if safety were paramount, we wouldn't be in space</li> <li>• <b><u>Accurately follow procedural steps</u></b> without skipping a step</li> <li>• <b><u>Effective teamwork</u></b> to complete airlock ops safely and efficiently</li> <li>• <b><u>Well-written procedures and human factors considerations</u></b> can make a huge difference (e.g., green bar on touchscreen checklist tracking progress)</li> </ul>	<ul style="list-style-type: none"> <li>• <b><u>Always aim to be ahead of schedule so that you can slow work tempo if needed</u></b>; better to slow down than to rush</li> <li>• <b><u>Formulate and discuss plan the night before with crewmates</u></b>; make sure everybody is on the same page</li> <li>• <b><u>Calling out procedural steps</u></b> while completing them can help you keep track of progress and make sure everyone is on the same page</li> <li>• <b><u>Check multiple pieces of data</u></b> to make sure they all make sense with each other. If the data don't make sense, wait for next data pass to make conclusion</li> <li>• <b><u>Learn from experience to make certain checks even if they aren't on checklist</u></b> (e.g., the adhesive strength of Valsalva device on inside of helmet)</li> <li>• <b><u>Evaluate data</u></b> to assess if a bad data pass is due to something wrong with the suit or due to human error</li> </ul>	<ul style="list-style-type: none"> <li>• <b><u>As support IV, suit donning is one of the most difficult and safety critical tasks</u></b> an astronaut can execute</li> <li>• <b><u>Prep Ops are more critical than Post Ops</u></b></li> <li>• <b><u>Incorrect suit donning</u></b> can impact EVA timeline and task completion</li> <li>• <b><u>Poor suit fit</u></b> can be detrimental to task performance</li> <li>• <b><u>Completing UIA procedures incorrectly</u></b> (flipping wrong switches or in wrong order) can lead to delays</li> <li>• <b><u>Improperly following pre-breathe protocol</u></b> can increase risk of DCS</li> <li>• <b><u>Incorrectly assembling suit</u></b> (e.g., arms on wrong sides)</li> </ul>

# Knowledge Audit



Inspection of Surroundings		
<i>Aspects of Expertise</i>	<i>Cues and Strategies</i>	<i>Why difficult?</i>
<ul style="list-style-type: none"> <li>• <b><u>Maintain situation awareness (SA)</u></b></li> <li>• <b><u>Maintain good communication with MCC</u></b>, moving fast to plan and set up task ahead of time</li> <li>• <b><u>Formulate a geological hypothesis about what you're seeing</u></b>; hypothesis will help you interpret subsequent findings in the field</li> <li>• <b><u>Ability to identify subtle differences in lunar landscape</u></b> that may have geological implications</li> <li>• <b><u>Leverage other areas of expertise</u></b>; e.g., rock climbing experience helped with tether awareness and is an accurate analog for the cognitive state of EVA (i.e., making continual progress against time while managing safety and completing tasks)</li> </ul>	<ul style="list-style-type: none"> <li>• <b><u>Inspect surroundings</u></b> and route to identify efficiencies in movement</li> <li>• <b><u>Process a lot of environment information</u></b> (elevation, boulder placement, lighting) at once, unlike a rover</li> <li>• During geological callouts, aim to provide <b><u>the optimal amount of information</u></b> (no more, no less), as other teammates may also be using the voice loop</li> <li>• <b><u>Know where it is most critical to allocate cognitive resources</u></b> (related to danger and mission importance)</li> <li>• <b><u>Identify when you can "zen out"</u></b> a bit in less critical moments to help maintain spare capacity for more critical moments</li> <li>• <b><u>Keep communications succinct and clearly signal end of communication</u></b> (e.g., saying "over") to help with communication delay</li> <li>• <b><u>Good satellite imagery and data from autonomous expeditions</u></b> will greatly aid humans on the ground on the Moon and Mars</li> </ul>	<ul style="list-style-type: none"> <li>• <b><u>Low illumination</u></b> on lunar surface will make it difficult to accurately judge surroundings</li> <li>• <b><u>Need to stay safe while continually moving forward</u></b> on the timeline in an efficient manner</li> <li>• <b><u>Multi-tasking</u></b>; inspection of surroundings for geology occurs as soon as traverse starts</li> </ul>

# Knowledge Audit



Sample Identification		
Aspects of Expertise	Cues and Strategies	Why difficult?
<ul style="list-style-type: none"> <li>• <b><u>Understand your current location</u></b> so you can place the sample in that context</li> <li>• <b><u>Identify the correct sample</u></b> based on the mission science objectives</li> <li>• <b><u>Accurately describe the sample</u></b> based on geological training</li> <li>• <b><u>Understand sample in the context of the geological hypothesis and narrative</u></b> that you have formed</li> </ul>	<ul style="list-style-type: none"> <li>• <b><u>Use cue cards and cuff checklists</u></b> to jog memory</li> <li>• <b><u>IV/MCC can help cognitively offload</u></b> some of the operator role (e.g., navigation) from the EV so that they can focus on doing good geology in the field</li> <li>• <b><u>Successful sample identification relies on effective performance of multiple successive steps</u></b> (i.e., knowing where you are, knowing what your hypothesis is, knowing what to expect, knowing how to interpret sample in the context of this knowledge)</li> </ul>	<ul style="list-style-type: none"> <li>• <b><u>Difficult to remember and accurately use geological terminology</u></b> to describe samples while managing suit, navigation, consumables monitoring, and other mission objectives</li> <li>• <b><u>Noticing subtle differences in geological samples</u></b> will be difficult in the low illumination conditions on the lunar surface</li> <li>• <b><u>Difficult to keep track of smaller details in samples</u></b> when doing a lot of observations</li> <li>• <b><u>Lunar samples won't differ hugely in color and texture</u></b>, making it more critical to notice subtle differences</li> </ul>

# Knowledge Audit



## Sample Collection: Rock/Regolith

<i>Aspects of Expertise</i>	<i>Cues and Strategies</i>	<i>Why difficult?</i>
<ul style="list-style-type: none"> <li>• <b><u>Understand the geological narrative</u></b> of the area that the sample is in (e.g., what caused the observable features, what kind of samples are likely to be present)</li> <li>• <b><u>Understand the best location to obtain sample</u></b> on the rock</li> <li>• <b><u>Know how to document sample</u></b> with pictures at appropriate angles and distances</li> <li>• <b><u>Know how to bag sample without contaminating it</u></b></li> <li>• <b><u>Use sampling tools safely and effectively</u></b></li> <li>• <b><u>Assemble tools correctly</u></b> using fine motor skills</li> <li>• <b><u>Track and use the correct equipment</u></b> (e.g., drive tube) for regolith sampling</li> </ul>	<ul style="list-style-type: none"> <li>• <b><u>Sampling from the optimal location on the rock</u></b> and in the right environment can reduce workload required to collect sample</li> <li>• <b><u>Keeping track of tool cart and stowage space</u></b> to save resources if space is limited</li> <li>• <b><u>Chip samples take more effort to collect</u></b> than other rock sample types (rake, float)</li> <li>• <b><u>Hand fatigue can be reduced</u></b> by swapping orientation of hammer and chisel or switching hands</li> <li>• <b><u>Let the hammer work for you</u></b> by using the mass of the hammer instead of swinging it harder</li> </ul>	<ul style="list-style-type: none"> <li>• <b><u>Hand fatigue</u></b> from using tools (hammer and chisel)</li> <li>• <b><u>Curvature of helmet may make it harder to see</u></b> sample at certain angles</li> <li>• <b><u>Could break or damage a tool</u></b> if used incorrectly</li> <li>• <b><u>Could impact helmet or suit with tool if used improperly</u></b> and potentially cause suit decompression</li> </ul>

# Knowledge Audit



## Surface Mobility

<i>Aspects of Expertise</i>	<i>Cues and Strategies</i>	<i>Why difficult?</i>
<ul style="list-style-type: none"> <li>• <b><u>Ability to move in the spacesuit</u></b> (change postures, positions) effectively</li> <li>• <b><u>Understand limits of the spacesuit and one's own body</u></b> so you don't cause injury</li> <li>• <b><u>Physical workload impacts cognitive workload</u></b>; mentally "shut down" when struggling with high physical workload and pain</li> <li>• <b><u>Transport tool cart</u></b> over uneven terrain and inclines/declines</li> </ul>	<ul style="list-style-type: none"> <li>• <b><u>Suit adaptation is most notable in the beginning of an EVA</u></b>, will likely be an adaptation period on lunar surface initially with improvement as astronauts adapt to moving in suits in partial gravity</li> <li>• Know which <b><u>body positions in suit</u></b> increase risk of injury</li> <li>• <b><u>Overcoming suboptimal suit fit</u></b> to accomplish task</li> <li>• <b><u>Use of extension handles on tools can</u></b> make them easier to use while in suit</li> <li>• <b><u>Working smart</u></b> in a spacesuit using everything available to you (e.g., rigidity of suit can be used for leverage in microgravity)</li> </ul>	<ul style="list-style-type: none"> <li>• <b><u>Suboptimal suit fit</u></b> can require moving one's body in specific ways to achieve movement necessary to complete task effectively</li> <li>• <b><u>No perfect analog for moving in spacesuit in lunar gravity</u></b>; there will be some adaptation for astronauts on lunar surface</li> <li>• <b><u>Potential error includes moving in suit in such a way that increases risk of injury</u></b></li> </ul>

# Knowledge Audit



Maintenance Tasks		
<i>Aspects of Expertise</i>	<i>Cues and Strategies</i>	<i>Why difficult?</i>
<ul style="list-style-type: none"> <li>• <b><u>Draw upon previous training and experience</u></b> to execute procedures and use hardware correctly</li> <li>• <b><u>Complete maintenance safely</u></b> and ensure that hardware being maintained stays viable and reliable</li> <li>• <b><u>Identify when something looks amiss</u></b> and address that first, then focus on task completion</li> <li>• <b><u>Understand the relationship between equipment functioning and environmental factors</u></b> that the equipment may affect—for example, a piece of equipment may appear to be functioning but expected temperature is not changing, indicating a need for maintenance</li> </ul>	<ul style="list-style-type: none"> <li>• Equipment failure can require <b><u>real-time modification of mission activities</u></b> (e.g., suit deconfiguration) that excludes the equipment that has malfunctioned</li> <li>• <b><u>Maintaining continuity of task progress</u></b>; starting a complex task then being assigned to another task has a cognitive cost</li> <li>• <b><u>Having teammates with compatible working styles</u></b> (e.g., similar levels of attention to detail, similar working speeds)</li> <li>• <b><u>Sometimes necessary to use tools intended for one task to complete another task</u></b> depending on tool location and availability</li> <li>• <b><u>Use the current procedural step to automatically trigger memory of the step that follows</u></b> so that it's more like muscle memory</li> <li>• <b><u>Check different pieces of data</u></b> to make sure they all make sense with each other; if they don't, wait for next data pass to make conclusion</li> </ul>	<ul style="list-style-type: none"> <li>• <b><u>Keeping track of task progress for long and complex tasks</u></b> can be difficult with everything competing for your attention</li> <li>• <b><u>Missing a maintenance procedure step</u></b> could impact the viability and reliability of the hardware</li> <li>• <b><u>Language barriers and incompatible working styles</u></b> can slow task progress</li> <li>• <b><u>Low visibility on hardware due to low illumination</u></b> can negatively impact situational awareness</li> <li>• <b><u>Overly fixating on an off-nominal equipment signal can threaten situational awareness</u></b> for other important cues that may exist in environment</li> </ul>

# Knowledge Audit



## Payload Operations

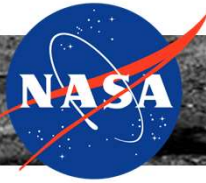
<i>Aspects of Expertise</i>	<i>Cues and Strategies</i>	<i>Why difficult?</i>
<ul style="list-style-type: none"><li>• <b><u>Manage time effectively</u></b></li><li>• <b><u>Always think ahead</u></b> with plan and contingency plan ready</li><li>• <b><u>Understand the constraints of science objectives</u></b> so you can react accordingly if you need to troubleshoot</li><li>• <b><u>Manage payloads while wearing spacesuit</u></b> (unlike ISS payloads)</li><li>• <b><u>Improvise as needed</u></b> given time constraints</li></ul>	<ul style="list-style-type: none"><li>• <b><u>Make changes in the moment when running short on time</u></b> to capitalize on available time and still accomplish science objectives</li><li>• <b><u>Move to a shorter task that you can complete instead of moving to planned next phase</u></b> if running low on time</li><li>• <b><u>Always engage in self-monitoring</u></b> during operations to understand how you can best make use of your time</li></ul>	<ul style="list-style-type: none"><li>• <b><u>The best laid plans can always go off-script</u></b>, so it's important to have a good understanding of what in the mission objective is okay and what isn't okay so that something off-nominal occurs you can react quickly</li><li>• <b><u>Managing payload while in suit involves understanding any suit limitations</u></b> and knowing how to manipulate the payload effectively</li></ul>

# Knowledge Audit



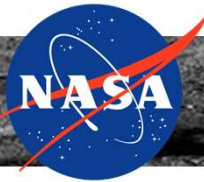
Traverse		
<i>Aspects of Expertise</i>	<i>Cues and Strategies</i>	<i>Why difficult?</i>
<ul style="list-style-type: none"> <li>• <b><u>Safe and efficient navigation</u></b> between lander and geology sites</li> <li>• <b><u>Know how to read map</u></b></li> <li>• <b><u>Make geological observations throughout the traverse</u></b></li> <li>• <b><u>Understand science objectives</u></b> and how to get to sites of interest</li> <li>• <b><u>Track consumables</u></b> accurately</li> <li>• <b><u>Maintain clear communication</u></b> with EV/IV/MCC about your location, intended destination, and remaining distance</li> <li>• <b><u>Keep track of timeline</u></b>, may need to adjust traverse if behind schedule</li> </ul>	<ul style="list-style-type: none"> <li>• <b><u>Use handrails, backstops, waypoints, and landmarks</u></b> to maintain accurate navigation</li> <li>• <b><u>Pay extra attention to slope, elevation, steep inclines/declines</u></b> for step placement so you don't not fall and cause potential injury</li> <li>• In EVA simulations, crewmembers sometimes <b><u>dig in heels for steep inclines/declines</u></b>, but loose rocks and regolith may make this a less effective strategy on the Moon</li> <li>• <b><u>Effective communication with IV can improve route efficiency</u></b> (e.g., was able to bypass some positions en route to robotic arm placement by giving instructions to crewmate controlling Canadarm2)</li> </ul>	<ul style="list-style-type: none"> <li>• <b><u>Getting lost</u></b> on the Moon is a life-threatening scenario</li> <li>• <b><u>Low illumination, long shadows, and permanently shadowed regions (PSRs)</u></b> will make judging terrain accurately difficult</li> <li>• <b><u>Terrain may not be exactly the same as the map</u></b> or what was expected in pre-brief materials</li> <li>• <b><u>Potential error includes overly following map</u></b> and ignoring terrain that may deviate from what map is indicating</li> <li>• <b><u>Even minor deviations from path</u></b> will require readjustment, communicating with EV/IV to reorient</li> </ul>

# Knowledge Audit



Worksite setup/cleanup		
<i>Aspects of Expertise</i>	<i>Cues and Strategies</i>	<i>Why difficult?</i>
<ul style="list-style-type: none"> <li>• <b>Effective preparation in advance</b> with a comprehensive pre-brief of science objectives, geology sites, and associated tool preparation</li> <li>• <b>Ability to organize</b> worksite so that you don't lose track of tools or samples</li> <li>• <b>Check tools and samples frequently</b> to rapidly notice if something has been misplaced</li> <li>• <b>Understand how to store samples properly</b> without contaminating them</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Prioritize any actions that have safety implications first</b>, then turn to task at hand</li> <li>• <b>Set up tools in specific order</b> to help you stay organized when collecting and storing samples</li> <li>• <b>Regularly check</b> that all tools and samples are present to save yourself time looking for them later</li> <li>• <b>Organization</b> during setup can make cleanup easier</li> <li>• Whenever leaving a worksite, <b>observe surroundings for any safety-relevant cues</b> (e.g., status of safety equipment, hazards in path)</li> </ul>	<ul style="list-style-type: none"> <li>• Challenging to <b>keep track of multiple tools and various equipment</b> across multiple worksites</li> <li>• <b>Multi-tasking</b>; must keep track of tools and equipment while also completing science objectives, traversing, communicating with MCC, and conducting safety checks</li> <li>• <b>Leaving behind a tool</b> can impact ability to achieve subsequent science objectives and add to timeline if you go back to retrieve it</li> </ul>

# Knowledge Audit Summary



- **Decision-making** during EVA must simultaneously balance safety, time constraints, and mission objectives
- **Maintaining situational awareness (SA)** is a key target of cognitive workload
  - **Factors that increase SA** include sufficient ground/IV support, sufficient sleep, clear visuals on environment, manageable physical workload
  - **Factors that decrease SA** include insufficient ground/IV support, fatigue due to insufficient sleep, poor visuals on environment (e.g., due to shadows, bright sunlight, or other obstruction), overly fixating on an off-nominal signal (e.g., unexpected equipment signal), and high physical workload (e.g., pushing heavy tool cart up steep incline)
- **High physical workload increases cognitive workload**
  - EVA is physically demanding, and the physical demands of EVA may increase cognitive workload independent of cognitive demands
  - Cognitive resources can be depleted as crewmember focuses their effort on managing the physical load, managing any presence of pain, and physically completing the task at hand

# Knowledge Audit Summary



- **A good teammate** can offload cognitive workload; a suboptimal teammate (e.g., due to incompatible working or learning styles) can add to cognitive workload
- **It is critical to have extensive pre-mission training and well-written procedures**, but crew must be able to effectively draw upon that experience and documentation during the mission
  - **Human factors considerations** can help design procedure checklists that are easy to navigate (e.g., touchscreen checklist with green bar indicating current step)
- **EVA Prep Ops** is one of the most safety critical tasks an astronaut can execute, with the cognitive demand higher for the support IV than the EV
- **Navigation during traverse on the lunar surface** will be challenging due to the visually similar landscape, lack of landmarks, low illumination, and permanently shadowed regions; getting lost on the Moon can be a life-threatening scenario
- **Sample identification** is a highly cognitively demanding task; challenges include remembering the scientifically precise geological terminology, being able to visually identify subtle differences in samples in low lighting conditions, and identifying samples accurately to ground science team while also managing consumables, communication, navigation, and suit mobility

# Simulation Scenario

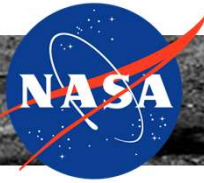


- **Purpose:** Provides important job context that allows probing around issues such as situation assessment, how assessment impacts a course of action, and potential errors that could be made
- **Scenario:** Incapacitated Crew Rescue (ICR); extravehicular crewmember 1 (EV1) has strained their back while conducting field geology 2 kilometers away from the Human Landing System (HLS) and has become incapacitated on the surface of the Moon, requiring rescuing by the other crewmember (EV2)
  - Expert was asked to imagine that they are the crewmember on the Moon who has not been incapacitated in the incident (EV2)
  - Expert listed the major events that would characterize their response in this situation



Image Credit: NASA

# Simulation Scenario



## Incapacitated Crew Rescue (ICR)

Events	Actions	Assessment	Critical Cues	Potential Errors
1. Determine injured crewmember status	<ul style="list-style-type: none"> <li>• Traverse to injured crewmember if separated</li> <li>• Ask what happened, if they can walk, how much pain they are experiencing</li> </ul>	<ul style="list-style-type: none"> <li>• Injured crewmember says they can't walk, verbally reports high level of pain</li> </ul>	<ul style="list-style-type: none"> <li>• Injured crewmember's body position, degree of mobility, facial expression, verbal report of pain</li> </ul>	<ul style="list-style-type: none"> <li>• Underestimating injured crewmember's verbal or nonverbal pain indicators</li> <li>• Failing to address more urgent issue if present (e.g., suit puncture)</li> </ul>
2. Check ICR procedures	<ul style="list-style-type: none"> <li>• EV refers to cuff checklist for correct ICR procedures</li> </ul>	<ul style="list-style-type: none"> <li>• Level of specificity determined in cuff checklist</li> <li>• Limitations of what procedures can be done in this scenario</li> <li>• Level of autonomy</li> </ul>	<ul style="list-style-type: none"> <li>• Making sure all individuals (EV, IV, MCC) are in agreement on the ICR procedures required in this specific situation</li> <li>• Everyone referring to the same procedures</li> </ul>	<ul style="list-style-type: none"> <li>• EV choosing the wrong cue card and wrong procedures for ICR scenario</li> <li>• Disconnect between procedures EV and MCC are referring to</li> <li>• Overreliance on cue card</li> </ul>

# Simulation Scenario



## Incapacitated Crew Rescue (ICR)

Events	Actions	Assessment	Critical Cues	Potential Errors
3. Communicate with MCC and IV crewmember	<ul style="list-style-type: none"><li>• Report conditions, actions, needs to MCC</li><li>• Listen for further instructions from MCC</li><li>• Update IV on situation if not already aware so they can go ahead and configure airlock for return</li></ul>	<ul style="list-style-type: none"><li>• Flight surgeon develops plan and makes recommendation while rest of team assesses impact of recommendation on timeline and science objectives</li></ul>	<ul style="list-style-type: none"><li>• Instructions from MCC/flight surgeon</li><li>• Clarity of communication given lunar communication delay</li></ul>	<ul style="list-style-type: none"><li>• Miscommunication, providing too much/too little detail, not providing enough situational awareness to MCC</li><li>• Assuming MCC would know something that they don't</li></ul>
4. Secure worksite	<ul style="list-style-type: none"><li>• Salvage as much science as possible while prioritizing injured crewmember safety</li></ul>	<ul style="list-style-type: none"><li>• Confirm all tools and samples are present</li><li>• Prioritize retrieving samples over tools if last EVA of mission</li></ul>	<ul style="list-style-type: none"><li>• Location of tools and samples in worksite at time of injury</li><li>• MCC guidance on status of science objectives and remaining timeline</li></ul>	<ul style="list-style-type: none"><li>• If injury occurs early in the mission, leaving tools behind at worksite may preclude further science objectives</li></ul>

# Simulation Scenario



## Incapacitated Crew Rescue (ICR)

Events	Actions	Assessment	Critical Cues	Potential Errors
5. Configure ICR transport device	<ul style="list-style-type: none"><li>De-configure device if current configuration is not ICR compatible</li><li>Move transport device to a flat surface if on an incline</li></ul>	<ul style="list-style-type: none"><li>If device is on an incline, it may not be safe for injured crewmember</li><li>Device is undamaged and has all equipment (e.g., straps) needed for securing crewmember</li></ul>	<ul style="list-style-type: none"><li>Flatness of lunar landscape where injury has occurred</li><li>Rocks, craters, or other obstacles in path</li></ul>	<ul style="list-style-type: none"><li>Improperly de-configuring transport device</li><li>Failure to stabilize transport device before loading injured crewmember</li></ul>
6. Secure injured crewmember to ICR transport device	<ul style="list-style-type: none"><li>Assist injured crewmember onto transport device; if not capable, strap crewmember and haul onto device</li></ul>	<ul style="list-style-type: none"><li>Whether injured crewmember is securely fastened to ICR transport device</li><li>Which direction injured crewmember is facing (impacts visual on facial expressions)</li></ul>	<ul style="list-style-type: none"><li>Injured crewmember's level of mobility</li><li>Location of straps and other ICR-assistive equipment</li></ul>	<ul style="list-style-type: none"><li>Failing to properly secure crewmember to transport device, risking further injury</li><li>Missing step in procedures as off-nominal scenario means less training</li></ul>

# Simulation Scenario



## Incapacitated Crew Rescue (ICR)

Events	Actions	Assessment	Critical Cues	Potential Errors
7. Traverse back to lander with injured crewmember	<ul style="list-style-type: none"><li>• Ask MCC if there are any hazards on route back to lander</li><li>• Look at map along with MCC instruction</li><li>• Walk forward with injured crewmember either being pushed or pulled</li><li>• Build in waypoints for checking on navigation, consumables, and injured crewmember's status on return route</li></ul>	<ul style="list-style-type: none"><li>• Identify flattest and least hazardous path (i.e., free of craters, PSRs, boulders) back to lander</li><li>• Identify path that both crewmember and MCC agree upon</li></ul>	<ul style="list-style-type: none"><li>• Level of consumables remaining for both crewmembers</li><li>• Hazards on traverse route not anticipated by MCC</li><li>• Slope of traverse route</li><li>• Lighting of traverse route (avoid shadows as they could conceal hazards)</li></ul>	<ul style="list-style-type: none"><li>• Not factoring in consumable rate change due to emergency scenario</li><li>• Slope identification can be challenging on lunar surface; could be on a slope without realizing it</li><li>• A path that initially seems like a shortcut could have steep slope on other side of incline</li><li>• Losing track of location in the heat of the moment and getting lost</li></ul>

# Linkage Analysis



EVA Tasks		EVA Task	Knowledge, Skills, & Abilities (KSAs)	Importance Rating	Cognitive Demand Rating
EVA Prep/Post Ops					
Inspection of Surroundings		<b>Inspection of Surroundings</b> - Photography - Inspection	Lunar topography		
Sample Identification			Location of craters		
Sample Collection - Rock			Camera operations		
Sample Collection - Regolith			Suit lighting operations		
Surface Mobility					
Maintenance	<b>How important is this KSA for effective performance of this task?</b> 0: not important   1: somewhat important   2: important   3: very important   4: critical				
Payload Operations	<b>How much cognitive and perceptual activity do you think is required for this KSA?</b> 0: Low ----- 100: High				
Public Affairs Operations					
Traverse					
Worksite setup/cleanup					

# Linkage Analysis

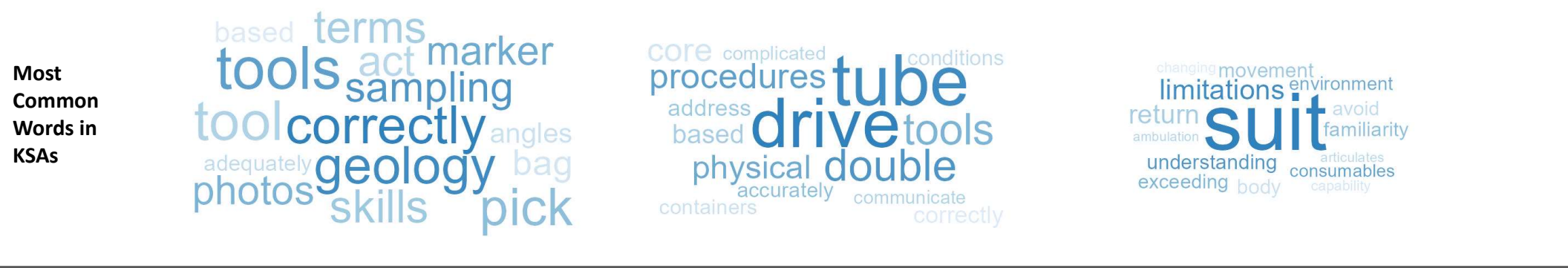


EVA Task	EVA Prep/Post Ops	Inspection of Surroundings	Sample Identification																		
<b>Most Common Words in KSAs</b>																					
<b>High Cognitive Demand KSA</b>	<i>"Suit and hatch emergency operations knowledge"</i>	<i>"Navigational capabilities, navigational tool usage"</i>	<i>"Describing geology"</i>																		
<b>KSA Ratings</b>	<table border="1"> <thead> <tr> <th>Rating</th> <th>Mean (SD)</th> </tr> </thead> <tbody> <tr> <td>Importance</td> <td>3.20 (0.86)</td> </tr> <tr> <td>Cognitive Demand</td> <td>50.7 (36.2)</td> </tr> </tbody> </table>	Rating	Mean (SD)	Importance	3.20 (0.86)	Cognitive Demand	50.7 (36.2)	<table border="1"> <thead> <tr> <th>Rating</th> <th>Mean (SD)</th> </tr> </thead> <tbody> <tr> <td>Importance</td> <td>3.14 (0.99)</td> </tr> <tr> <td>Cognitive Demand</td> <td>53.5 (23.4)</td> </tr> </tbody> </table>	Rating	Mean (SD)	Importance	3.14 (0.99)	Cognitive Demand	53.5 (23.4)	<table border="1"> <thead> <tr> <th>Rating</th> <th>Mean (SD)</th> </tr> </thead> <tbody> <tr> <td>Importance</td> <td>2.97 (0.88)</td> </tr> <tr> <td>Cognitive Demand</td> <td>47.1 (27.0)</td> </tr> </tbody> </table>	Rating	Mean (SD)	Importance	2.97 (0.88)	Cognitive Demand	47.1 (27.0)
Rating	Mean (SD)																				
Importance	3.20 (0.86)																				
Cognitive Demand	50.7 (36.2)																				
Rating	Mean (SD)																				
Importance	3.14 (0.99)																				
Cognitive Demand	53.5 (23.4)																				
Rating	Mean (SD)																				
Importance	2.97 (0.88)																				
Cognitive Demand	47.1 (27.0)																				

# Linkage Analysis



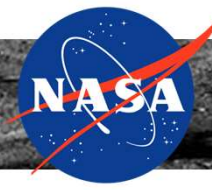
EVA Task	Sample Collection: Rock	Sample Collection: Regolith	Surface Mobility
----------	-------------------------	-----------------------------	------------------



High Cognitive Demand KSA	<i>"Communicate with geology terminology to ground"</i>	<i>"Know geology terms"</i>	<i>"Understanding suit limitations"</i>
---------------------------	---	-----------------------------	---

KSA Ratings	Rating	Mean (SD)	Rating	Mean (SD)	Rating	Mean (SD)		
	Importance	3.10	(0.85)	Importance	3.27	(0.47)	Importance	3.56
Cognitive Demand	38.8	(20.0)	Cognitive Demand	61.4	(13.4)	Cognitive Demand	55.0	(33.5)

# Linkage Analysis



EVA Task	Maintenance Tasks	Public Affairs Operations	Traverse
----------	-------------------	---------------------------	----------

Most Common Words in KSAs



High Cognitive Demand KSA	<i>"How to do maintenance for each type of equipment"</i>	<i>"Public speaking, communicating the big picture of what we're doing and why it's important to humanity"</i>	<i>"Navigation skills"</i>
---------------------------	---	--	----------------------------

KSA Ratings	Rating	Mean (SD)	Rating	Mean (SD)	Rating	Mean (SD)
	Importance	2.83 (0.41)	Importance	2.90 (1.29)	Importance	3.33 (0.71)
Cognitive Demand	83.3 (5.16)	Cognitive Demand	42.0 (20.2)	Cognitive Demand	88.3 (5.59)	

# Linkage Analysis



## Traverse

### Knowledge

- Traverse path
- Geological features in your surroundings

### Skills

- Apply knowledge of consumables rate to adjust your own body
- Manage secondary tasks and prioritize effectively

### Abilities

- Ability to navigate and read map accurately
- Multi-task

## Maintenance Tasks

### Knowledge

- Design and function of your equipment
- How the hardware works

### Skills

- Use your equipment to repair hardware
- Manipulate hardware without damaging it
- Maintain your own safety

### Abilities

- Plan ahead so that you bring the right equipment
- Manage time effectively

## Sample Collection: Regolith

### Knowledge

- Geology terminology and how to describe samples accurately
- Drive tube procedures

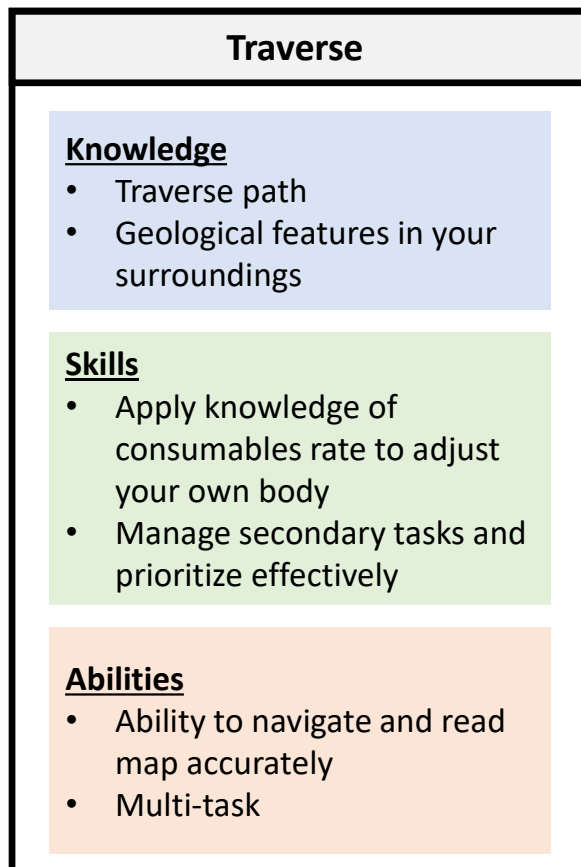
### Skills

- Drive tube sampling
- Trenching
- Manage equipment or improvise if part breaks

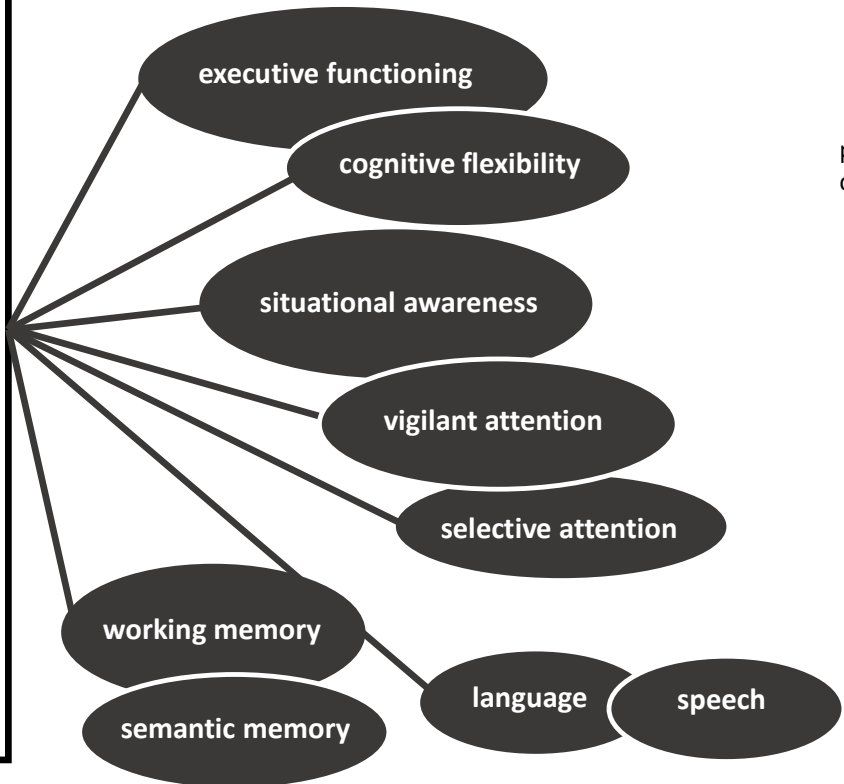
### Abilities

- Physical ability to drive tube into lunar soil
- Keep track of all samples, tools, and equipment

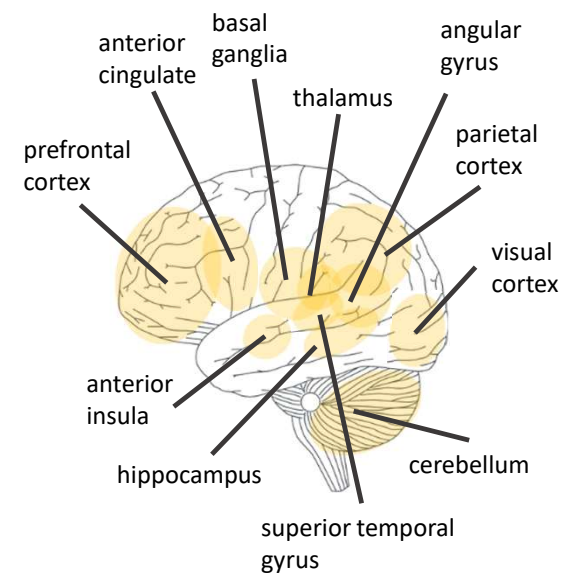
# Linkage Analysis



## Cognitive Domains



## Neural Correlates

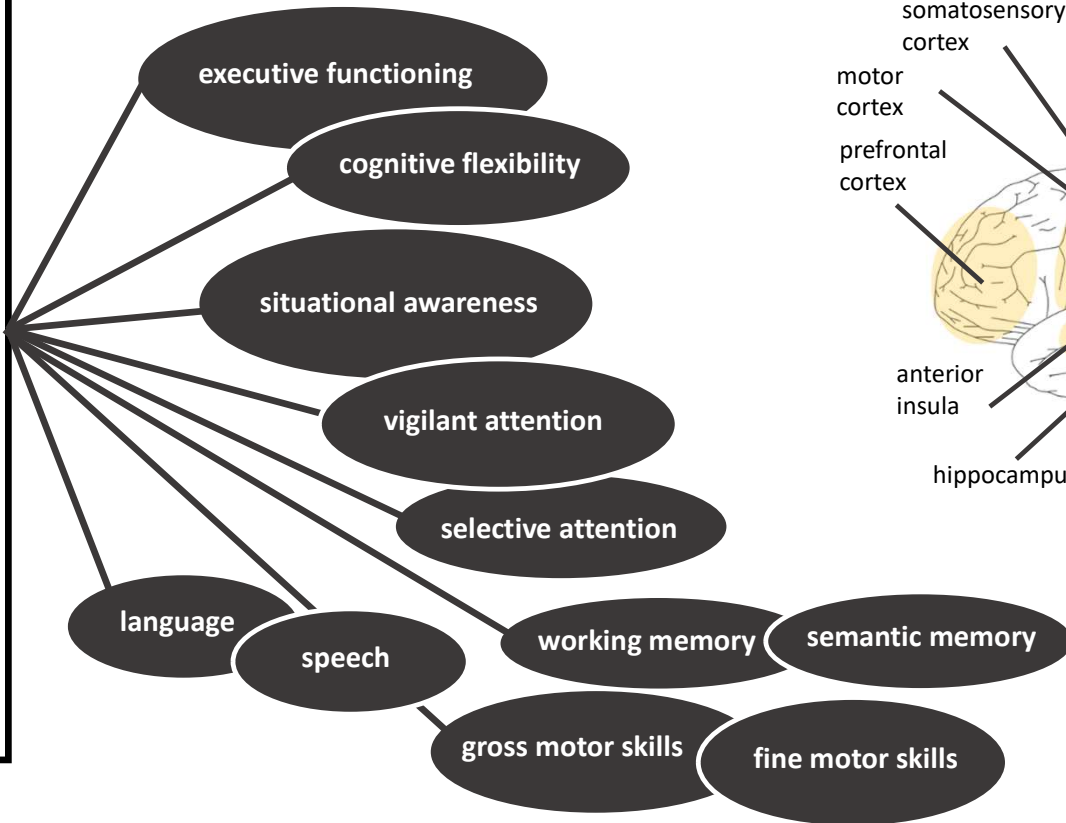


# Linkage Analysis

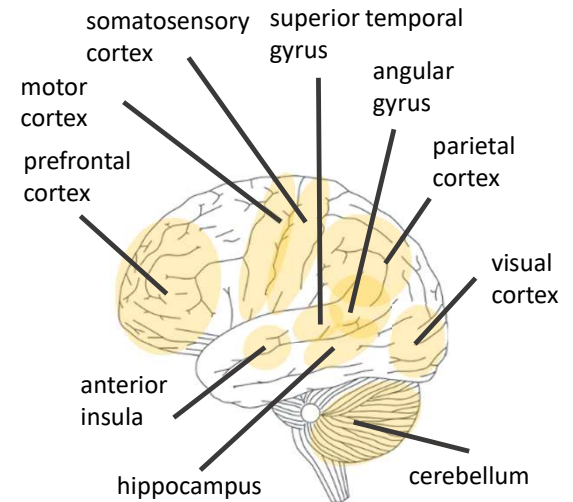


Maintenance Tasks
<b>Knowledge</b> <ul style="list-style-type: none"><li>• Design and function of your equipment</li><li>• How the hardware works</li></ul>
<b>Skills</b> <ul style="list-style-type: none"><li>• Use your equipment to complete maintenance</li><li>• Manipulate hardware without damaging it</li><li>• Follow procedures</li></ul>
<b>Abilities</b> <ul style="list-style-type: none"><li>• Plan ahead so that you bring the right equipment</li><li>• Manage time effectively</li></ul>

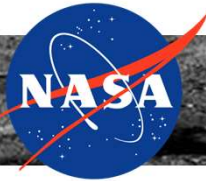
## Cognitive Domains



## Neural Correlates



# Linkage Analysis



### Sample Collection: Regolith

**Knowledge**

- Geology terminology and how to describe samples accurately
- Drive tube procedures

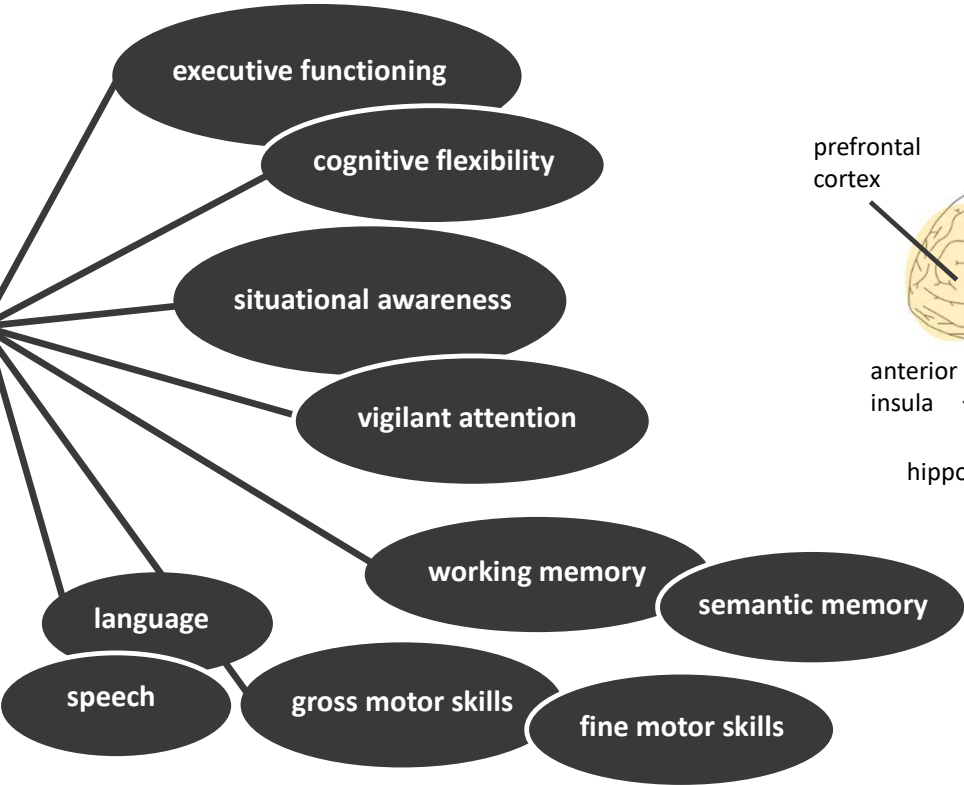
**Skills**

- Drive tube sampling
- Trenching
- Manage equipment or improvise if part breaks

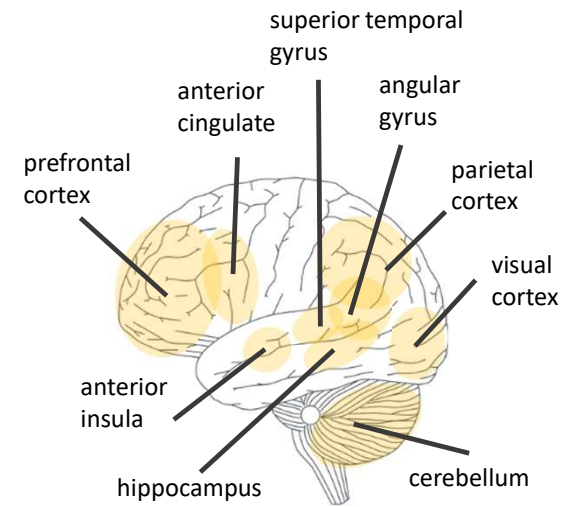
**Abilities**

- Physical ability to drive tube into lunar soil density
- Keep track of all samples, tools, and equipment

### Cognitive Domains



### Neural Correlates

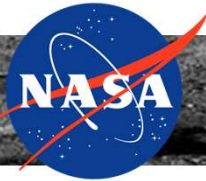


# Contributing Factors

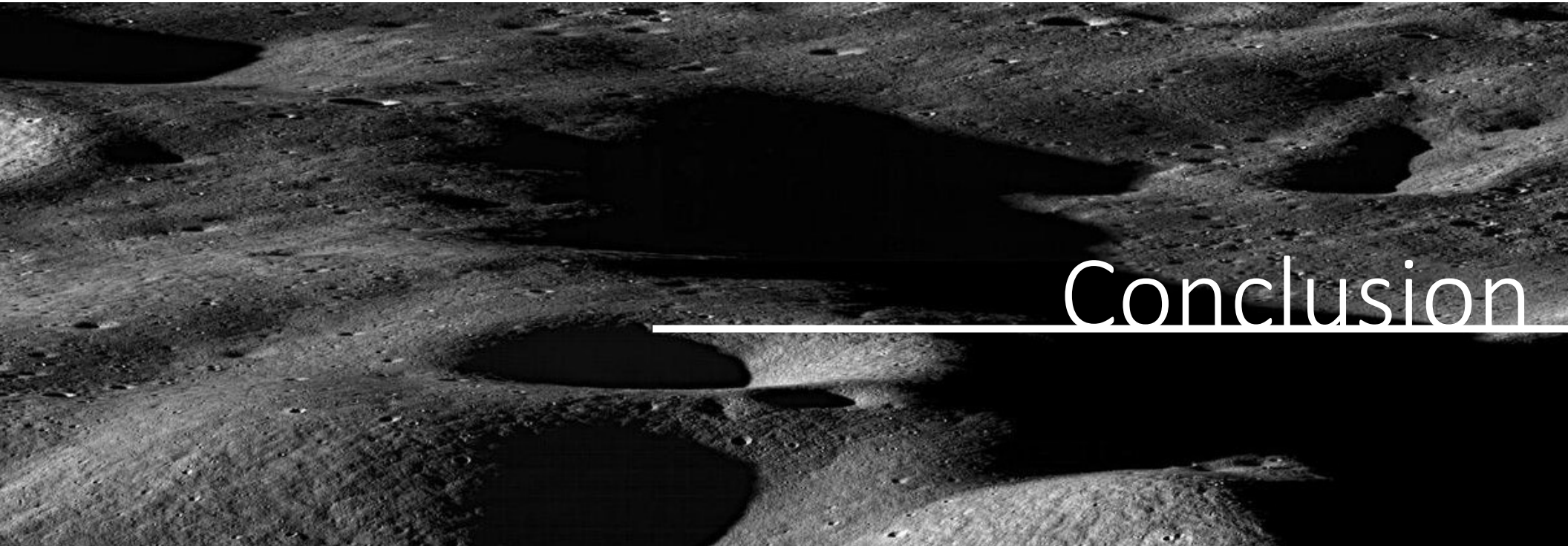


Contributing Factor	Summary of Feedback
<p>What do you think are the most likely and consequential critical safety incidents related to decrements in cognitive performance that could occur on future EVAs on the Moon and Mars?</p>	<ul style="list-style-type: none"><li>• <b><u>Off-nominal and emergency scenarios</u></b> like incapacitated crew rescue (ICR) will be highly cognitively demanding for crew; one's brain can shut down during high-pressure situations making it difficult to process new information, especially if fatigued</li><li>• <b><u>Errors in navigation during traverse:</u></b> getting lost on the Moon is a life-threatening scenario; navigation during traverse will be challenging due to high-contrast shadows and visually similar lunar landscape; crew will need to track consumables and navigate simultaneously; falls could lead to injury; driving a lunar rover adds another cognitively challenging element to navigation</li><li>• <b><u>Errors in following procedures</u></b> such as missing steps will increase as crew becomes more physically and cognitively fatigued (especially without rover and during high tempo EVA cadence)</li><li>• <b><u>Errors in donning and doffing the suit</u></b> due to lack of sleep and fatigue would be detrimental to safety and science objectives</li><li>• <b><u>Inadequate sleep</u></b> due to complexity of mission phases leading up to surface EVA</li><li>• <b><u>Decrements in situational awareness</u></b> could lead to neglect of consumables monitoring</li><li>• <b><u>Decrements in attention to detail</u></b> due to physical and cognitive fatigue; crew must be able to pay attention to small details for extended periods of time; crew must also balance paying attention to small details with keeping in mind the big picture (e.g., science objectives)</li><li>• <b><u>Errors in dust mitigation and inspection</u></b> could lead to hazardous lunar dust exposure</li></ul>

# Contributing Factors



Contributing Factor	Summary of Feedback
<p>How do you think a 5-12s lunar (voice) communication delay might impact an astronaut's cognitive performance on future Artemis missions?</p>	<ul style="list-style-type: none"><li>• Communication delay will lead to <b><u>repetition and possible talking over each other</u></b></li><li>• <b><u>Frustration and annoyance</u></b> are likely to be common experiences due to the communication delay, which can have negative impacts on cognitive performance</li><li>• <b><u>Off-nominal scenarios</u></b> will make any communication delay especially impactful as crewmembers will need to communicate with MCC in a time-sensitive and stressful situation</li><li>• <b><u>There is a need to develop guidelines</u></b> for when and how to stop speaking to clarify communications; procedure words used in military and aviation settings (e.g., "over", "copy") should be worked into EVA ground training and used consistently</li><li>• <b><u>Good team composition and extensive pre-mission training</u></b> will help astronauts learn the communication patterns of their fellow crewmembers, which can facilitate more effective communication</li><li>• It is important to consider the <b><u>cumulative impact</u></b> of communication delay on the <b><u>frequency and nature of communications</u></b> over the course of a mission</li><li>• <b><u>Current communication frequency norms on ISS</u></b> may not be realistic for future Artemis missions with communication delay</li><li>• <b><u>This is an area in need of further research</u></b></li></ul>



Conclusion

# Cognitive Demands Table



Difficult Cognitive Element	Why Difficult?	Cues and Strategies Used	Cognitive Domains Used
<ul style="list-style-type: none"> <li>Maintaining sufficient situational awareness</li> </ul>	<ul style="list-style-type: none"> <li>Fatigue</li> <li>Large amounts of information in environment</li> </ul>	<ul style="list-style-type: none"> <li>Support from MCC/IV</li> <li>Knowing when you can conserve cognitive resources</li> </ul>	<ul style="list-style-type: none"> <li>Sustained attention (vigilance)</li> <li>Selective attention</li> </ul>
<ul style="list-style-type: none"> <li>Navigation during traverse</li> </ul>	<ul style="list-style-type: none"> <li>Lack of visually distinct landmarks on moon, low illumination, long shadows, few navigation aids</li> <li>No perfect ground analog for partial gravity EVA</li> </ul>	<ul style="list-style-type: none"> <li>Good maps and pre-brief materials</li> <li>Frequent communication with MCC/IV to confirm location</li> <li>Handrails, backstops, waypoints, and landmarks to orient</li> </ul>	<ul style="list-style-type: none"> <li>Executive function</li> <li>Cognitive flexibility</li> <li>Working memory</li> <li>Language</li> <li>Reading comprehension</li> <li>Situational awareness</li> </ul>
<ul style="list-style-type: none"> <li>EVA Prep Ops as IV crewmember</li> </ul>	<ul style="list-style-type: none"> <li>Critical procedure; error could endanger life of crewmates</li> <li>Large number of procedural steps</li> <li>Requires teamwork</li> </ul>	<ul style="list-style-type: none"> <li>Aim to be ahead of schedule; easier to slow tempo than speed up</li> <li>Formulate and discuss plan the night before with crewmates</li> <li>Call out procedural steps while completing them</li> </ul>	<ul style="list-style-type: none"> <li>Executive function</li> <li>Working memory</li> <li>Sustained attention (vigilance)</li> <li>Situational awareness</li> <li>Language/Speech</li> <li>Reading comprehension</li> </ul>
<ul style="list-style-type: none"> <li>Managing safety, time constraints, and mission objectives simultaneously over the entire course of the EVA</li> </ul>	<ul style="list-style-type: none"> <li>Requires decision-making and cognitive flexibility on relative importance of time management, safety, and mission objectives</li> </ul>	<ul style="list-style-type: none"> <li>Safety is a tool for successful task completion</li> <li>MCC can offload some of the cognitive load of managing time, safety, and mission objectives</li> </ul>	<ul style="list-style-type: none"> <li>Executive function</li> <li>Cognitive flexibility</li> <li>Situational awareness</li> <li>Sustained attention (vigilance)</li> </ul>

# Cognitive Demands Table



Difficult Cognitive Element	Why Difficult?	Cues and Strategies Used	Cognitive Domains Used
<ul style="list-style-type: none"> <li>Remembering geological terminology and accurately applying it to samples</li> </ul>	<ul style="list-style-type: none"> <li>Terminology is complex and specific to this scientific discipline</li> <li>Astronauts have diverse backgrounds and may not be geologists by training</li> <li>Lunar rocks are visually similar and geologically significant differences may be subtle</li> <li>Geological callouts occurring while also managing physical workload, navigating, tracking timeline</li> </ul>	<ul style="list-style-type: none"> <li>Extensive ground training in geology in lunar-like environments (e.g., Iceland)</li> <li>Cue cards and cuff checklists can help</li> <li>Geological callouts should be scientifically precise and succinct; excess communication can prevent other key communication on voice loops</li> </ul>	<ul style="list-style-type: none"> <li>Executive function</li> <li>Working memory</li> <li>Semantic memory</li> <li>Language/Speech</li> </ul>
<ul style="list-style-type: none"> <li>Off-nominal and emergency scenarios</li> </ul>	<ul style="list-style-type: none"> <li>Hard to effectively simulate in ground training</li> <li>Stressful and unexpected</li> </ul>	<ul style="list-style-type: none"> <li>Cuff checklists can be referred to for certain emergency procedures (e.g., ICR)</li> <li>Effective communication with MCC is key</li> </ul>	<ul style="list-style-type: none"> <li>Executive function</li> <li>Cognitive flexibility</li> <li>Working memory</li> </ul>
<ul style="list-style-type: none"> <li>Lunar voice communication delay</li> </ul>	<ul style="list-style-type: none"> <li>5-12s delay can lead to talking over, frustration, miscommunication</li> </ul>	<ul style="list-style-type: none"> <li>Military procedure words (e.g., "over") used consistently in ground training</li> </ul>	<ul style="list-style-type: none"> <li>Executive function</li> <li>Language/Speech</li> <li>Working memory</li> </ul>

# Recommendations



- Crew pre-mission training should include **off-nominal and emergency scenarios** such as incapacitated crew rescue (ICR)
- **Situation Awareness (SA) should be systematically measured** in EVA simulation studies to characterize how and when there are decrements in SA that could affect performance
- **Physical workload and pain** should be recognized as factors that can impact cognitive workload and managed accordingly prior to, during, and following EVA
- **Adequate sleep** will be critical and especially challenging with new vehicles and complex mission phases
- Implement **procedure words** in ground training and in future missions to deal with communication delay
- Crew need as much **navigational aid** as technologically possible on the lunar surface
- Cue cards on crew suit cuffs should include **reminders of geological terms for callouts**
- MCC should consider **offloading some of the operator tasks of crew** while they are doing geology ops to maximize the likelihood that high-quality science is conducted on the lunar surface
- Astronauts on the lunar surface may need **extra time for suit mobility adaptation**, separate from traverse, or there is likely to be increased cognitive workload early in the EVA as crewmembers adapt to moving in the suit in partial gravity
- To maximize the cognitive offloading of effective teamwork, **crews should receive psychological education** on cognitive offloading and compatible and incompatible working styles



# Future Directions

# Unobtrusive Cognitive Performance Metrics

## Consumables monitoring

- Thermal Load/Temperature Control Valve (TCV)
- Oxygen
- Battery

## Physiological Responding

- Heart rate variability (HRV)
- Metabolic rate
- Electrodermal activity (EDA)
- Electroencephalography (EEG)

## Gait

- Human knee task range of motion
- Difference in human and suit task range of motion
- Relative coordination metric

## Location

- Time to each waypoint
- Overall course time
- Deviation from route

## Eye tracking

- Fixations
- Saccades
- Response time/latency

## Facial expression

- Facial Action Units (AUs)
- Blinking frequency
- Smiling/frowning

## Verbal

- Fatigue speech coding
- Geological callouts
- Auditory responding
- Anomaly reporting

## Tool usage

- Unintentional tool drops
- Tool use efficiency
- Tool use effectiveness

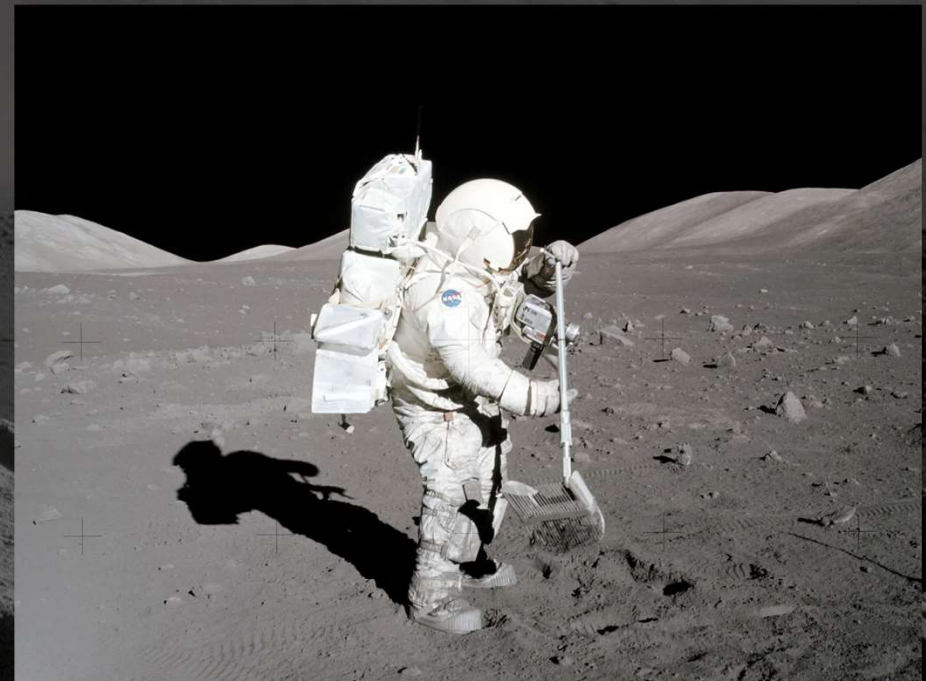
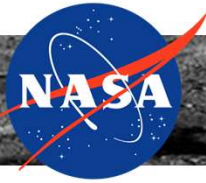


Image Credit: NASA

# Unobtrusive Cognitive Performance Metrics



## Auditory cognitive performance tests

### Digit Span Test

- Source: Soylu (2010), modified from Wechsler Memory Scale-III (WMS-III) (Wechsler, 1997)
- Procedure: Presented to NBL run EV subject during 5-min traverses to each geology site (x4)
- Stimuli: computer-spoken digits (1-9)
- Instructions: Please repeat the strings of numbers in the order you hear them
- Outcomes: mean reaction time, accuracy, lapses

### Psychomotor Vigilance Test

- Source: Modified version of Wilkinson Auditory Vigilance Test (Wilkinson, 1968)
- Procedure: Presented to NBL run EV subject during 5-min traverses to each geology site (x4)
- Stimuli: 500ms tone, Inter-stimulus interval: 2-1s
- Instruction: Please reply "TEST" when you hear the tone
- Outcomes: mean reaction time, accuracy, lapses

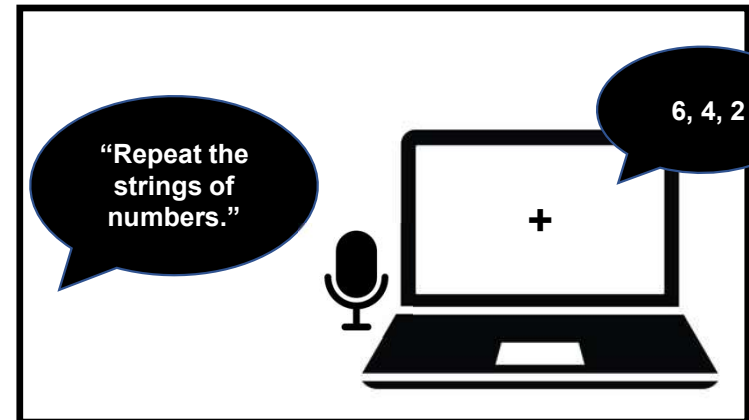
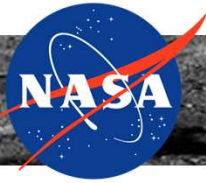


Image Credit: NASA

# Unobtrusive Cognitive Performance Metrics



**Automatic fatigue and  
cognitive workload  
detection through facial  
and vocal cues**



*percentage of eyelid closure rate over time (PERCLOS)*  
Wierwille et al. (1994), Zhao et al. (2021)



*articulator velocity coordination and vocal creak*  
Heaton et al. (2020)

# Cognitive Performance Monitoring

## EVA Readiness

### Pre-EVA

- Informs cognitive readiness assessments that can be used at astronaut selection, crew selection, and training stages

## EVA Task Performance

### During EVA

- Unobtrusive metrics can inform predictive risk models
- Risk models can in turn inform automated decision-making tools

## EVA Impacts

### Post-EVA

- Post-hoc cognitive fatigue characterization
- Sleep and recovery recommendation
- Performance evaluation

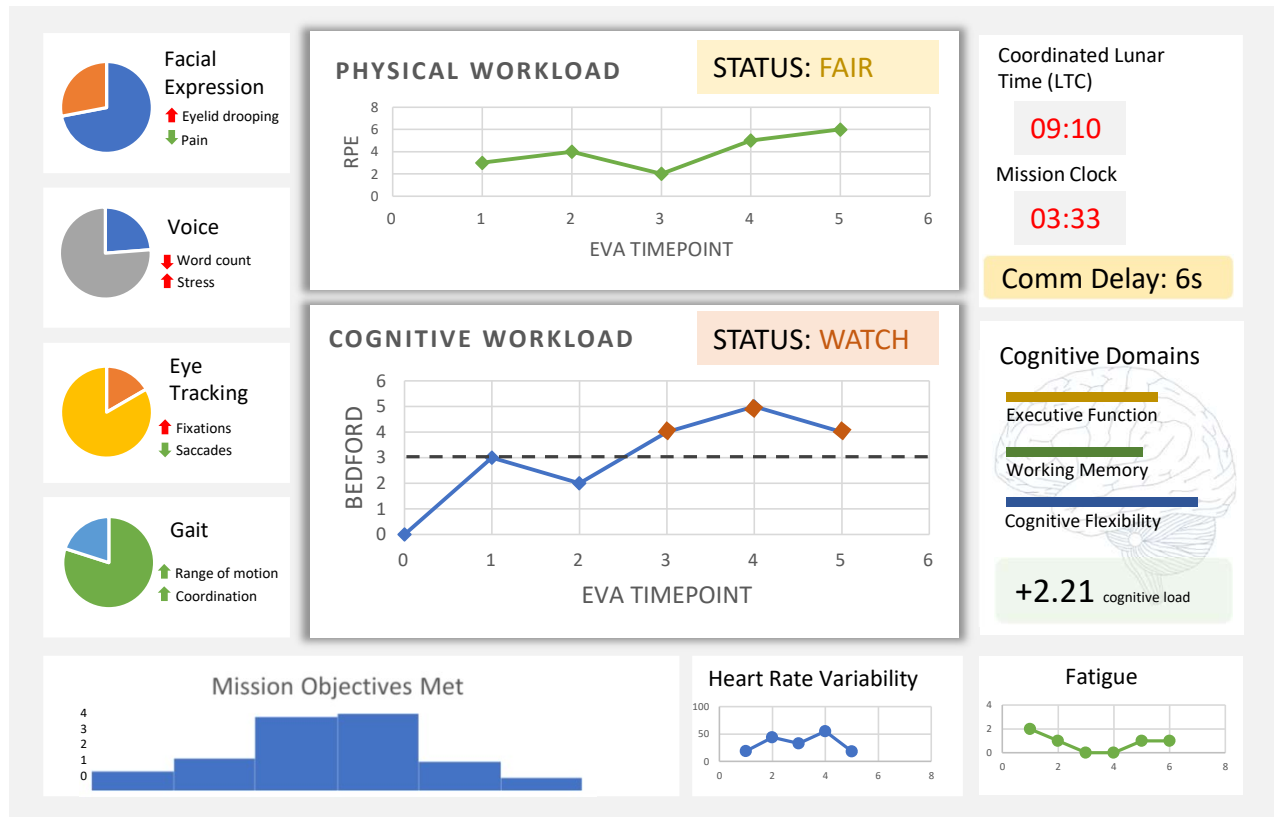
Image Credit: NASA

# Cognitive Performance Monitoring



## Cognitive performance monitoring dashboard concept

- Integrates physical and cognitive workload metrics
- Tracks self-reported and unobtrusive metrics
- AI integration of multi-modal data to provide high-level insights
- Highlights above-threshold observations
- Available to all consenting team members (MCC, flight surgeon, astronauts)
- Research needed on how viewing dashboard influences astronaut stress, mood, and performance



# Questions?

[steven.anderson@nasa.gov](mailto:steven.anderson@nasa.gov)



Image Credit: NASA