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# Performance Optimization for Lunar Extravehicular Activity Readiness (POLAR) Study: Methods Paper

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# Introduction

The Artemis Program is a multi-phased approach for human exploration beyond low Earth orbit, with the goal of sustained Lunar surface missions within the next decade [1, 2], ultimately laying the groundwork for crewed exploration of deep space [3]. The return of humans to the Moon will involve unique mission objectives, novel landing sites, and an increased frequency and duration of extravehicular activity (EVA) performed using updated tools and spacesuits. Together, these factors associated with Artemis exploration are expected to increase the physical demand associated with partial gravity (g) EVAs on the Moon to levels beyond what has been experienced during previous Apollo EVAs and microgravity EVAs performed on the International Space Station (ISS). Coupled with the potential for prolonged microgravity and partial g exposure, this demand necessitates the prioritization of physical fitness to protect crewmember health and safety, thereby helping to enable mission success. Currently, muscle strength and aerobic fitness standards for partial-g EVAs in NASA 3001 Standards (NASA-STD-3001) Revision C [4] have not been experimentally validated and it is currently unclear if these fitness standards are related to EVA performance. Relevant operational research is required to determine validity of these measures across a larger population and/or establish new thresholds to help protect the various facets of crew health and performance during planetary surface missions.

EVA operations are critical to the success of the Artemis Program and include key activities related to science, vehicle maintenance, and surface exploration. In comparison to EVAs performed during the Apollo era, Artemis Phase 1 EVAs are expected to be of increased duration of up to 8 hr [5], occurring at an increased frequency of up to 5 EVAs in one week [6, 7], and performed in a spacesuit nearly double in weight [8, 9]. Artemis design reference missions (DRM) are also slated to exceed the maximum Apollo duration of any manned surface mission (i.e., Apollo 17, 12 days) [10], exposing Artemis crewmembers to a greater length of time of microgravity and partial-g unloading (e.g., initial missions are expected to be ~14 days, but maybe up to 30 days) which may exacerbate deconditioning. Therefore, it is postulated that Artemis missions will require greater physical effort to perform specific tasks on the Lunar surface compared with previous Apollo missions. As such, keeping Artemis mission objectives in mind during the development of aerobic and muscle fitness standards may help ensure that astronauts are physically prepared prior to and during missions, in order to safely and successfully complete Lunar EVA tasks.

While a previous investigation, the Functional Mission Task (FMT) Study [11, 12], was conducted with the aim of developing a minimum set of muscle strength and aerobic fitness standards for successful completion of EVA-related tasks on exploration missions, several aspects of the study design make it difficult to apply to Artemis EVA performance. For instance, the use of various weighted suit conditions to simulate deconditioning increased the intensity of task performance but may not capture the performance impacts of deconditioning. Additionally, the EVA tasks completed within the study were chosen and developed prior to the publication of Artemis Concepts of Operations. Notably, the FMT study did not examine performance data in relation to NASA-STD-3001; therefore, it is unknown whether current standards for aerobic capacity and muscular strength (assessed through 1RM deadlift and bench press) are associated with successful simulated EVA performance.

To better understand which aspects of physical fitness may be most related to performance during Lunar surface operations and thereby help to inform the current NASA fitness standards, much can be learned from fields encompassing the "tactical athlete [13]." Other physically demanding professions such as law enforcement, military, or rescue professionals often require candidates to meet occupationally-relevant fitness standards [14]. The determination of such standards is a multistep process, including both objective and subjective measures, to determine tasks essential to occupational performance and identify the minimal fitness profile needed to meet physical demands of the job [15]. Notably, fitness is only one component which may contribute to the demands of astronaut selection, flight assignment, and occupational performance. Utilizing a framework to systematically determine which domains of fitness most contribute to relevant job tasks can aid in the refinement of current NASA-STD-3001 fitness standards.

Therefore, NASA's Exercise Physiology & Countermeasures Laboratory conducted the Performance Optimization for Lunar Extravehicular Activity Readiness (POLAR) study to identify and examine a comprehensive list of fitness tests (including NASA-STD-3001 assessments: 1-Repetition Maximum [1-RM] bench press and deadlift) and determine preliminary relationships between identified fitness parameters and novel Artemis-relevant tasks to help inform future investigations for the continued development of aerobic and muscular fitness standards for surface EVAs. This was accomplished through 1) a review of the literature relating fitness assessments to simulated or real

EVA performance to identify fitness tests that are most correlated with simulated EVA task performance [16]; 2) a task analysis following a modified framework for physical employment standards development to down select mission critical tasks; and 3) development and pilot testing of a novel, portable Artemis-relevant EVA task circuit to relate to a battery of fitness assessments. The current report describes the methodology used to complete the task analysis, EVA task circuit development, and the pilot study.

# Methods

## EVA Task Circuit Development

The ongoing effort to inform the NASA-STD-3001 necessitates evaluating identified fitness assessments to determine their relationship to exploration/Lunar EVAs. Because Apollo surface EVAs occurred more than 50 years ago when comprehensive fitness assessments were not utilized, research in analog (higher fidelity) and 1-g (lower fidelity) environments are used to inform the question, "How fit does a crewmember need to be to successfully complete Lunar mission tasks?" As an initial step in the validation process, pilot research in lower-fidelity environments can provide this insight before investing in higher-fidelity environments. As indicated by previously published research [16], an EVA "task circuit," which includes a series of EVA tasks performed in sequence, can be used as a surrogate measure for EVA performance. The POLAR project, which includes the development and testing of an Artemis-relevant EVA task circuit in relation to identified fitness metrics, is the preliminary step in NASA-STD-3001 expansion, laying the groundwork for other recently funded investigations. The Hi-Tempo EVA Study will assess fitness and task circuit performance in individuals performing simulated EVAs in both low and high-fidelity research environments, and data collected will provide further insight into the impacts of fitness on EVA performance.

To increase the utility of the EVA task circuit for inclusion in other Human Research Program-funded investigations and external investigations, the research team sought to develop the circuit in a way in which methods could be kept consistent across a variety of research scenarios (i.e., incorporated as performance metric performed before and after EVA simulations, exercise interventions, bed rest, etc.). For instance, equipment utilized in the circuit should be transportable and tasks should easily be performed in different laboratory or high-bay spaces, thereby allowing the future comparison of EVA task performance in different subject populations (e.g., healthy vs bed rest deconditioning). Another consideration for the task circuit was length of task circuit. Because Lunar simulations during higher fidelity investigations are expected to exceed 6+ hours, designing a task circuit that could be performed in a short amount of time (<20 minutes) would increase the feasibility of using it as an assessment before and after an intervention/exposure (e.g., EVA simulation, bed rest, spaceflight). Similarly, considering the potential for inclusion of the task circuit as a pre/post assessment in bed rest investigations, a longer high effort task circuit could increase the risk of injury in a deconditioned population.

### *EVA Task Analysis*

To develop a Lunar EVA task circuit for the characterization of Artemis-relevant EVA performance, a task analysis was performed following a modified framework utilized by the North Atlantic Treaty Organization (NATO) to develop employment standards (Figure 1) [15]. Although the aim of this task analysis was not to determine employment standards as the factors for determining astronaut candidacy, employment, or flight assignment extend beyond physical fitness, principles used by NATO were applicable to help create a novel EVA task circuit that could be used in a variety of research settings. The modified framework to develop the Artemis-relevant EVA task circuit is as follows: 1) achieve consensus on the definition of a "critical" task, 2) perform task analysis using a combination of objective and subjective methods to down select tasks for inclusion into the circuit, 3) develop the task circuit considering Artemis Concept of Operations (ConOps) and the ability to use the task circuit for future research, and 4) pilot test the task circuit in relation to a larger fitness battery identified through a review of literature and consideration for operational relevance (e.g., NASA-STD-3001).

First, the study team defined "critical tasks" as those in which failure to perform a critical EVA task would result in risk to life, safety, or failure to complete mission objectives. To initiate the task analysis, the study team used available documentation for Exploration EVA ConOps [6, 7] as well as prior relevant analog research to identify a compendium of potential Lunar operation tasks. **Table 1** describes the characterization of EVA tasks used to generate a total of 123 distinct tasks, encompassing a variety of intensities, body positions, and loads. Tasks were then grouped based on main task category and subtask (**Table 2**), in order to simplify survey development (See section "Survey Development") and subject matter expert (SME) consultation which was used to down select the tasks deemed most critical and physically impactful to mission operations.

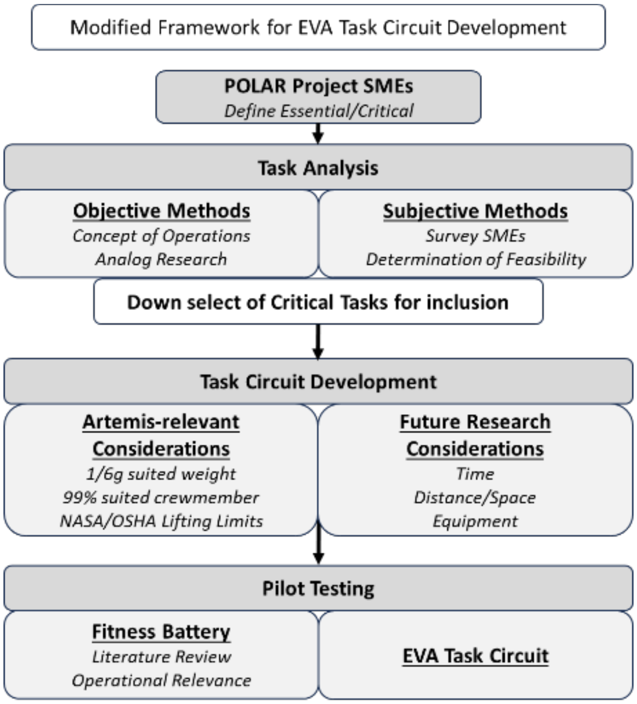


Figure 1: Modified Framework for the POLAR Extravehicular Activity (EVA) Task Circuit Development

*Table 1: Characterization of Extravehicular Activity (EVA) tasks from the Exploration Concepts of Operations (ConOps)*

| Task Characterization | Description |
|---|---|
| Body Positioning | Upright, Kneeling, Bent, Supine/Prone |
| Muscle Groups | Lower body, Upper body, Whole body |
| Ambulation | None, Minimal, Walking (flat terrain), Walking (up and down slopes), Walking (uneven terrain) |
| Upper Body Muscle Contraction | Minimal contraction, Static/Isometric, Dynamic/Isotonic |
| Lower Body Muscle Contraction | Minimal contraction, Static/Isometric, Dynamic/Isotonic |
| Load Type | Load Attached to Suit, Carrying Load, Pushing/Pulling Load, Other/Unknown |
| Upper Body Loads | No Significant Loading, Minimal Load (less than 5 lbs.), Moderate Load (5 to 30 lbs.), Heavy Load (> 30 lbs.), Variable Load (minimal to heavy), Other/Unknown |
| Level of Exertion | Low (RPE 6-10), Medium (RPE 11-15), High (RPE 16-20) |
| Upper Body Reach | None, Standard Workspace, Extended Workspace |
| Task Duration | < 1 minute, 1-5 minutes, 5-15 minutes, 15-60 minutes, Longer than 1 hour, Other/Unknown |
| Task Occurrence | Occurs in nearly all EVAs (90-100%), Occurs in most EVAs (~75%), Occurs in many EVAs (~50%), Occurs in some EVAs (~30%), Rarely Occurs in any EVA (<10%), Other / Unknown |
| Task Frequency | Every 1-30 minutes during EVA, Every ~1 hr during EVA, Every ~2 hrs during EVA, Total of 1-2 times during EVA, Other / Unknown |

*Rate of perceived exertion (RPE; scale 6-20).*

*Table 2: Extravehicular Activity (EVA) task and subtask categories*

| Main EVA Task Category | EVA Subtasks Include: |
|---|---|
| Sample collection | -Rock (float, chip, and rake samples)<br>-Regolith (bulk scoop, core sample [single], core sample [double], surface collection, and trench samples) |
| Maintenance tasks | -Mating/demating connectors<br>-Removing/installing fasteners<br>-Removing/installing hardware<br>-Cable management (burying, routing)<br>-Dust mitigation |
| Payload operations | -Transport payloads (with cart; varied terrain and loads)<br>-Transport payloads (without cart; caried terrain and loads)<br>-Deploy/retrieve payload |
| Traverse | -Traverse (without cart; short distance; varied terrain; limited loads)<br>-Traverse (without cart; long distance; varied terrain; limited loads) |
| Worksite setup/cleanup | -Tool retrieval/stowage<br>-Sample retrieval/stowage |
| Incapacitated crew rescue | -Temporary partial reliance<br>-Continuous partial reliance<br>-Continuous full reliance |
| Surface mobility | -Prone/supine recovery<br>-Descend/ascend ladder<br>-Descend/ascend steps |
| EVA prep/post ops | -Don/doff suit<br>-Open/close hatch |

### *Survey Development*

To quantify the criticality and physical demand of the EVA tasks identified in **Table 2**, a 41-question survey was developed through Microsoft Forms, using a combination of free answer (for respondent demographics), multiple choice, and Likert-scale questions. SMEs across several disciplines (e.g., exercise physiology, flight medicine, EVA operations, those with previous suited/EVA simulation experience, strength and conditioning, physical therapy, and spacesuit biomechanics/injury/physiology) were identified based on their background and association with NASA's Surface EVA Readiness and Performance Optimization working group. Respondents were provided a short reference guide regarding background to the project and descriptions of EVA subtasks (e.g., types of geological sample collection and tools, body positioning, and clarification of definitions) to help inform survey responses. Respondents were allowed 1 month to submit their responses.

Demographic information was collected to determine SME area of expertise and familiarity with Artemis EVA ConOps. The survey included the assessment of criticality, level of impact to mission success, and risk of injury for the Main EVA Tasks Categories (**Table 2**). Additionally, the survey assessed perceived physical demand of EVA subtasks (**Table 2**) and whether cardiorespiratory or muscular fitness would be necessary to complete a given task.

Survey results were assessed using a multi-step approach: 1) Majority Vote, 2) Decision Tree, and 3) Feasibility. First, the majority vote strategy was applied to three questions related to criticality, impact to mission success, and risk of injury for the Main EVA Tasks Categories. This process involved calculation of the frequency of disagree/agree votes; to determine if a task was deemed critical to mission success, a majority (>50%) of respondents needed to select either "Agree" or "Strongly Agree". Main EVA Task Categories with the highest frequency of majority vote were prioritized for potential inclusion into the task circuit. **Figure 2** demonstrates example output for Main EVA task category scoring.

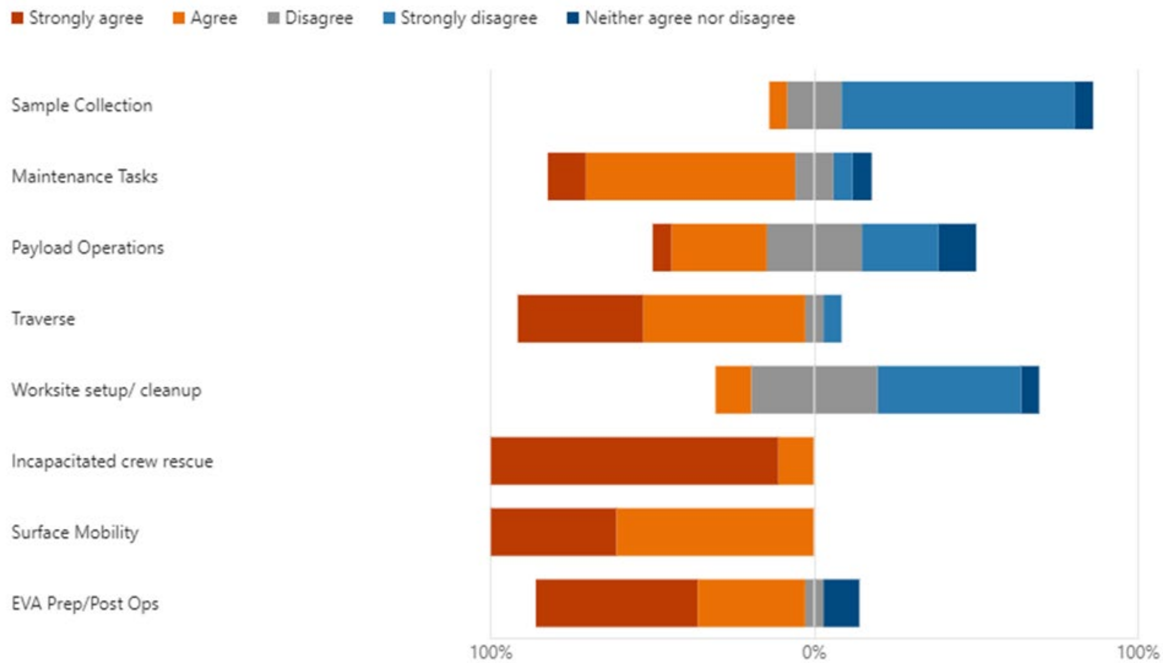
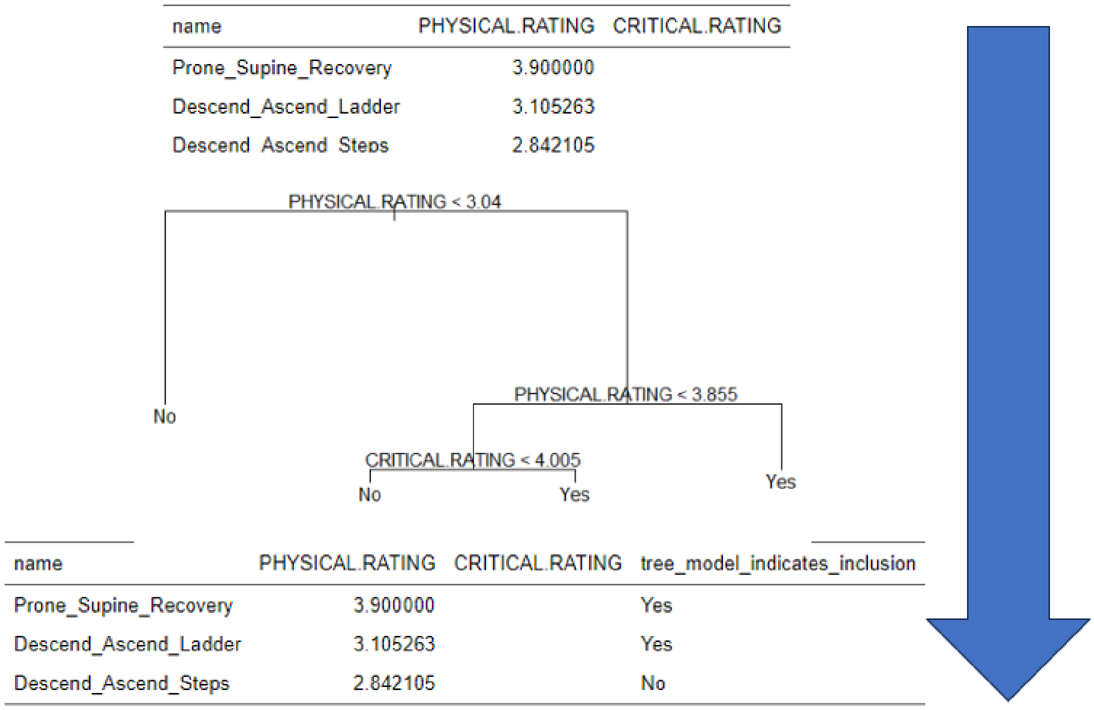



*Figure 2: Example survey question output*

Next, a decision tree algorithm (**Figure 3**) was developed in the programming language R using data from the Firefighter Candidate Physical Ability Test (CPAT) [17] to define the steps for scoring criticality and physical demand of EVA subtasks. Individual EVA subtasks captured within the Main EVA Task Categories were filtered through this decision tree. Likert scale responses for criticality and physical demand scores were converted to a numerical scale and averaged, with missing values removed. These responses were then filtered through the decision tree algorithm which output physical and critical ratings, as seen in **Figure 3** example. For subtasks to be classified as candidates for inclusion into the task circuit, CPAT-calculated thresholds were used in the algorithm, such that the subtask needed a physical rating greater than 3.855 or have a physical rating between 3.04-3.855 with a critical rating above 4.005. All individual EVA subtasks were ordered from highest to lowest, based on the decision tree physical and critical rating scores. Lastly, tasks had to meet a "feasibility" criterion. To maximize the utility of the EVA task circuit for use in future studies, the study team determined that the task circuit needed to be of reasonable length (e.g., could be completed 15-20 minutes), have a small footprint of testing space (to not interfere with other study testing), and must be portable to allow for consistent implementation across numerous testing sites. Tasks that met the feasibility criteria were incorporated into the POLAR EVA Task Circuit.



| name | PHYSICAL.RATING | CRITICAL.RATING |
|---|---|---|
| Prone_Supine_Recovery | 3.900000 | |
| Descend_Ascend_Ladder | 3.105263 | |
| Descend_Ascend_Steps | 2.842105 | |



| name | PHYSICAL.RATING | CRITICAL.RATING | tree_model_indicates_inclusion |
|---|---|---|---|
| Prone_Supine_Recovery | 3.900000 | | Yes |
| Descend_Ascend_Ladder | 3.105263 | | Yes |
| Descend_Ascend_Steps | 2.842105 | | No |

*Figure 3: POLAR decision tree algorithm derived from Firefighter Candidate Physical Ability Test*

### *Survey Results*

A total of 20 SMEs completed the survey, a majority having expertise in space suit biomechanics/injury, physiology, exercise physiology, and athletic training (**Figure 4**). Additionally, at least 90% of respondents had some familiarity with Artemis ConOps, with a majority (65%) having at least moderate familiarity (**Figure 5**).

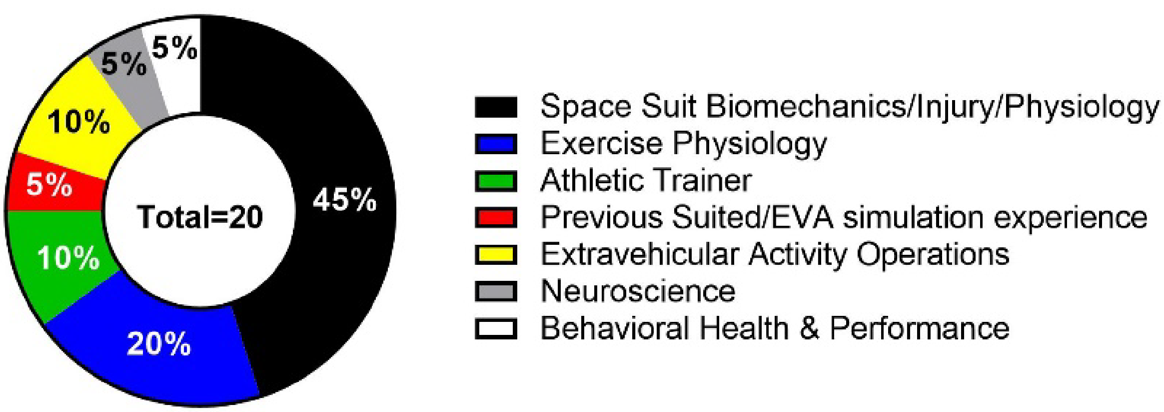



*Figure 4: Subject Matter Expert background breakdown*

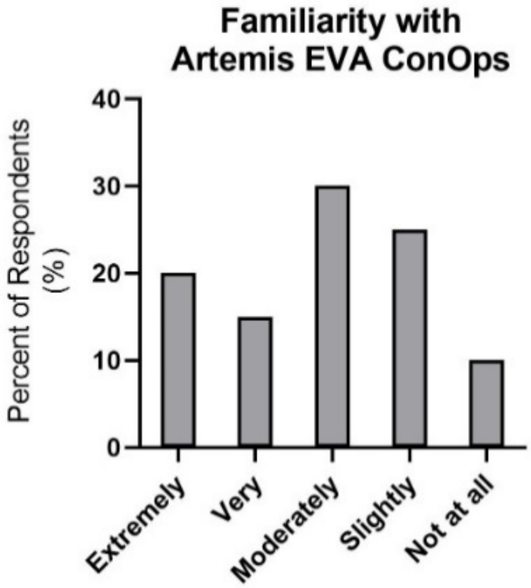



*Figure 5: Subject matter expert familiarity with Artemis Extravehicular Activity (EVA) Concepts of Operations (ConOps)*

Results from the majority vote strategy (**Table 3**), the first step in identifying tasks for inclusion into the POLAR EVA circuit, highlighted several main task categories in which most respondents deemed tasks as critical, having significant mission impact, and having potential for injury. These tasks included: surface mobility, incapacitated crew rescue (ICR), and traverse. All respondents classified surface mobility and ICR to be critical, whereas 90% of respondents classified traverse to be a critical task. Traverse, surface mobility, and ICR were classified as having significant mission impact by 100%, 95%, and 70% of respondents, respectively. At least 85% of respondents determined that completing these tasks predisposed a crewmember to a high risk of injury. While other tasks such as sample collection and payload operations scored highly for mission impact, the failure to complete these tasks was not seen as endangering a crewmember.

Results from the decision tree algorithm identified 16 EVA subtasks for potential inclusion (**Table 4**) into the task circuit based on the resultant physical and critical rating, while excluding 12 EVA subtasks due to low rating. Subtasks with the highest physical and critical ratings included continuous full reliance ICR, continuous partial reliance ICR, and transport payloads (without cart). Eight of 16 EVA subtasks were deemed feasible for short, portable task circuit. Various sample collection and maintenance tasks would have required a sandbox or simulated geology sites, which limited feasibility for performance in a variety of testing locations. Additionally, tasks requiring a cart or suit were not considered feasible due to availability and potential transport of such equipment. The final four distinct tasks for inclusion into the POLAR task circuit were continuous full reliance ICR, payload transport (without cart), prone recovery, and traverse (without cart) (**Table 4**; highlighted in green). Due to the similarity in ICR tasks, continuous full reliance ICR (i.e., one crewmember is fully reliant on another to return to lander) was selected over continuous partial reliance (i.e., one crewmember needs assistance from other to return to lander), because of the increased intensity of the task to maneuver a fully incapacitated crewmember. Three of the four tasks (ICR, traverse, prone recovery) were from the main task categories that met the majority vote criteria for criticality, mission impact, and injury, while one task (payload transport) was among the top-rated subtasks for physical and critical decision tree rating. These tasks also fit the criteria for “perform surface EVA physical functions on foot,” which was identified as a critical task function in the abridged “Generalizable Skills and Knowledge or Exploration Missions” report [18].

*Table 3: Survey majority vote results.*

| Main EVA Task Category | Majority Vote Outcomes | | |
|---|---|---|---|
| | Criticality | Mission Impact | Injury Risk |
| Sample Collection | 1 | 20 | 12 |
| Maintenance Tasks | 14 | 19 | 5 |
| Payload Operations | 6 | 20 | 13 |
| Traverse | 18 | 20 | 17 |
| Worksite setup/cleanup | 2 | 17 | 3 |
| Incapacitated crew rescue | 20 | 14 | 20 |
| Surface mobility | 20 | 19 | 19 |
| EVA Prep/Post Ops | 17 | 19 | 8 |

*For each outcome, the number indicates how many subject matter experts scored the task as critical, having significant mission impact, or injury risk. Red indicates that the scores do not meet the majority vote cut off (>50% of respondent), while green indicates meeting the majority vote.*

*Table 4: Physical and critical rating decision tree output for extravehicular activity (EVA) subtask category*

| EVA Subtask Category | Category | Physical Rating | Critical Rating | Feasibility | Final Inclusion |
|---|---|---|---|---|---|
| Continuous Full Reliance | Incapacitated crew rescue | 5.00 | 4.05 | Yes | Yes |
| Continuous Partial Reliance | Incapacitated crew rescue | 4.55 | 4.05 | Yes | |
| Payload Transport (without cart; varied terrain and loads) | Payload Operations | 4.45 | 4.80 | Yes | Yes |
| Regolith core sample [double] | Sample Collection | 4.15 | 4.80 | No | |
| Payload Transport (with cart; varied terrain and loads) | Payload Operations | 4.15 | 4.80 | No | |
| Traverse (without cart; long distance; varied terrain; limited loads) | Traverse | 4.05 | 4.55 | Yes | Yes |
| Regolith core sample [single] | Sample Collection | 3.90 | 4.80 | No | |
| Regolith trench sample | Sample Collection | 3.90 | 4.80 | No | |
| Prone/Supine Recovery | Surface Mobility | 3.90 | 4.74 | Yes | Yes |
| Rock chip sample | Sample Collection | 3.60 | 4.80 | No | |
| Cable Management (burying, routing) | Maintenance Tasks | 3.50 | 4.35 | No | |
| Don/Doff Suit | EVA Prep/Post Ops | 3.26 | 4.50 | No | |
| Temporary Partial Reliance | Incapacitated crew rescue | 3.25 | 4.05 | Yes | |
| Deploy/Retrieve Payload | Payload Operations | 3.21 | 4.80 | Yes | |
| Traverse (without cart; short distance; varied terrain; limited loads) | Traverse | 3.20 | 4.55 | Yes | |
| Removing/installing hardware | Maintenance Tasks | 3.06 | 4.35 | Yes | |

## EVA Task Circuit

Results from the task analysis led to the inclusion of 4 unique tasks in the 16.5-minute POLAR EVA Task Circuit (**Table 5**; Appendix A). These included incapacitated crew rescue (continuous full reliance; ICR; 4 minutes), payload transport (2 minutes), prone recovery (30 seconds) and traverse (4 minutes), with 2 minutes rest between tasks. The timing and order of tasks was determined through internal research team trials of different variations of the tasks, to minimize cumulative fatigue between tasks. To simulate the approximate additional weight of a suit in Lunar gravity ($1/6^{th}$ g) [9], subjects were outfitted with weighted garments, totaling 50.4 lbs, applied to the trunk, wrists, waist, ankles, and feet (**Figure 6**). For the payload transport task, sandbag/kettlebell weights were chosen after consulting with SMEs on NASA suited mass lifting limits (i.e., 67.5 kg or 25 lb earth equivalent). Because this weight likely would not elicit a differential response compared to the traverse tasks, weight was chosen to approach the NIOSH/OSHA weight limit of 23 kg [19]. Additionally, throughout the test, subjects wore a heart rate monitor (POLAR, Kempele, Finland) and portable metabolic analysis device (COSMED K5, Rome, Italy) to measure the physiological responses to each task.

*Table 5: POLAR extravehicular activity (EVA) task circuit description*

| Task | Duration (minutes) | Protocol |
|---|---|---|
| Incapacitated Crew Rescue (Continuous Full Reliance) | 4 | Subject reverse pulls weighted sled across the length of the mat, releases handle, repositions to opposite side and repeats |
| Rest Period 1 | 2 | |
| Payload Transport | 2 | Subject walks laps around mats while transporting kettlebells (KB), at the end of each lap subject lifts/places KBs to different heights, grabs new KBs |
| Rest Period 2 | 2 | |
| Prone Recovery | 0.5 | Starting in prone position with hands at chest height, subject pushes upwards, sliding one foot forward, and then stands to full height before repeating |
| Rest Period 3 | 2 | |
| Traverse | 4 | Subject walks laps around designated perimeter of mats |
| **Total time** | **16.5** | |

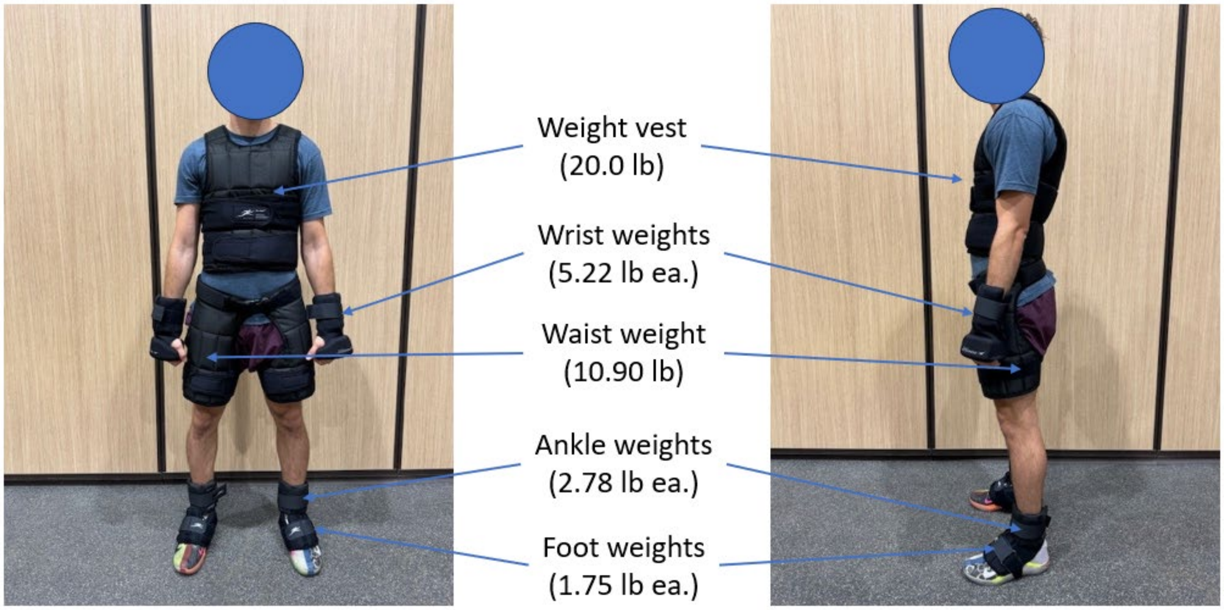



*Figure 6: Weighted vest and accessories for POLAR task circuit*

The task circuit was conducted within a 27' x 14' unobstructed highbay space at NASA John Space Center, with 5 3' x 4' rubber mats placed end to end in the center (**Figure 7**). The dimensions of the task circuit space were determined based on estimates of available space in other highbays and research locations. The rubber mats were selected as a transportable method to maintain a consistent dragging surface (friction) during the ICR task; because it is unknown what surfaces may be available in other research locations and dragging the sled on different surfaces (e.g., carpet, tile, cement) may result in differing physical effort, and the rubber mats were chosen to reduce variability in task performance in different settings. Equipment included a rescue sled (Skedco), 45-lb plates (2; Iron Grip), 10-lb plates (2; Iron Grip), 30-lb sandbags (4; Exerbell; filled with sand to weight 30-lb each), weighted vest (20-lb; Ironwear), ankle weights (2.78 lb; Ironwear), shoe weights (1.75 lb; Ironwear), wrist weights (5.22 lb; Ironwear), waist weight (10.9 lb; Ironwear), workout bench (Quantum Fitness Corp or other comparable bench with height of 18.5-19"), and timer (Appendix B).

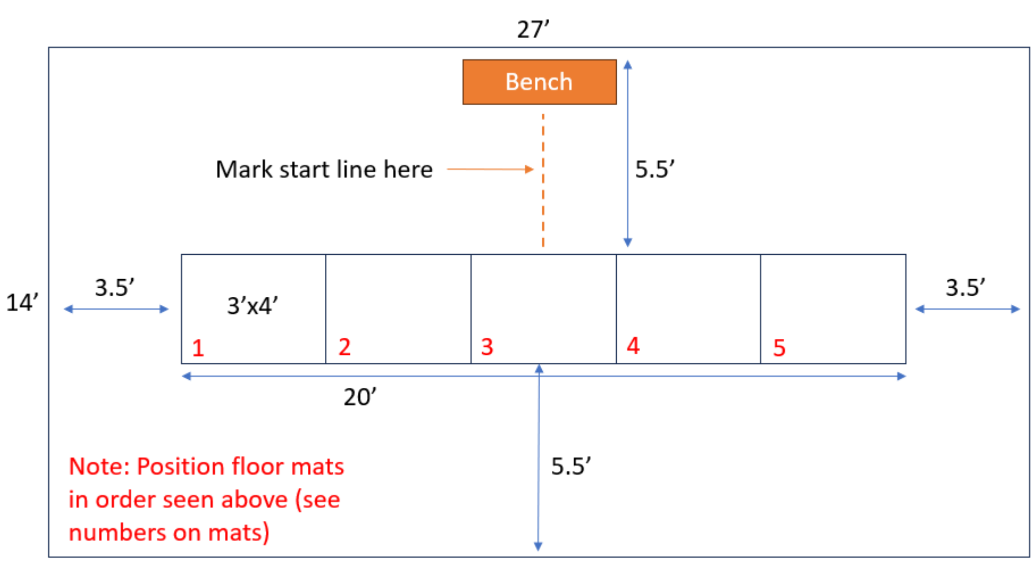



Figure 7: Layout and dimensions of POLAR task circuit

*Incapacitated crew rescue (continuous full reliance;* ***Figure 8****)*: Although unexpected, the ability to return an incapacitated crewmember to the lander is a critical, potentially life-saving effort. To perform this task, weight plates totaling 110lb were strapped to a rescue sled (representative of 99th percentile crewmember [20] + estimated exploration suit mass [9],  in Lunar-g) which was positioned at one end of the 20' rubber mat track. With the sled (8' in length) lined up at the end of the rubber track, the subject pulled the sled from starting position toward the opposite end of the track. Once the sled reached the end of the track (full length to complete one length/lap = 12' to end of track, one direction), the subject repositioned themselves around the opposite end of the sled and dragged in the reverse direction. The subject continued to drag the sled along the path for a total of 4 minutes, with total distance covered as the outcome of interest. At the end of the 4-minute task, the subject rested for 2 minutes.

*Figure 8: Incapacitated crew rescue*

*Payload Transport (****Figure 9****)*: During an EVA, crewmembers will need to load and unload scientific payloads/equipment, likely at various heights, while maintaining a safe lifting movement. To perform this task, a bench was placed to the side of the rubber track, at the approximate halfway mark. Two 30lb sandbags were placed on the bench and two 30lb sandbags were placed on the ground in front of the bench. To start the test, the subject picked up the sandbags from the floor and walked around the perimeter of the 20' rubber mats, until they reached the bench again and placed the sandbags down. The subject then picked up the sandbags from the elevated position on the bench and completed a lap around the mat (1 lap= 46'). The subject continued these laps for a total of 4 minutes, with total distance covered as the outcome of interest. At the end of the 4-minute task, the subject rested for 2 minutes.

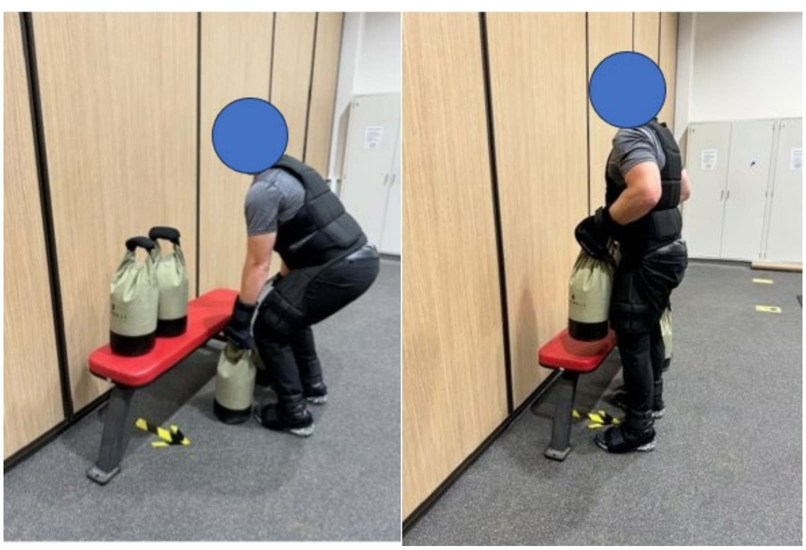


*Figure 9: Payload Transport*

*Prone Recovery (Figure 10)*: Falling on the Lunar surface occurred on several occasions during Apollo missions [21], often requiring multiple attempts to gain enough momentum to push themselves back up to standing position. Given the increased mass of exploration suits, the inability to return to standing could impact safety and mission success. To perform this task, the subject began in a prone position with hands at chest level (**Figure 10**, panel 1). The subject then performed a pushup motion and slid one foot to waist height (**Figure 10**, panel 2), before moving to stand fully upright (**Figure 10**, panel 3)- this complete motion counted as 1 repetition. The subject returned to prone position, to complete as many repetitions as possible, with correct posture, in a 30-second period. At the end of this task, the subject rested for 2 minutes.

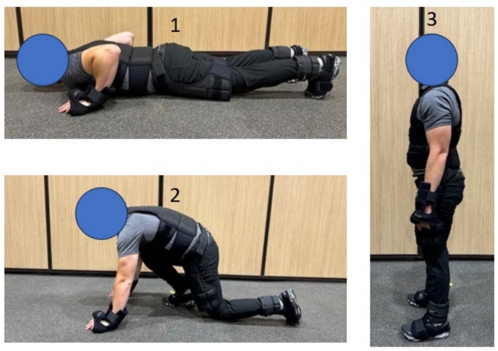



*Figure 10: Prone Recovery*

*Traverse:* Crewmembers will be expected to traverse over varied distances during exploration missions and may have to traverse at the end of an EVA, when consumables may be limited. Without the ability to simulate the uneven surface on the Moon in this portable task circuit, the traverse task occurred at the end of the circuit for increased challenge. For this task, the subject walked around the perimeter of the mat area maintaining a walking motion (i.e., one foot in contact with ground at all times; 1 complete lap= 46') for a 4-minute duration. The outcome of interest is the total distance covered.

## EVA Task Circuit Scoring

*Incapacitated Crew Rescue:* Study operators recorded the full lengths/laps completed (1 length/lap = 12ft). If subject had an incomplete final length at the end of the 4-minute task period, the operators recorded the additional distance covered. Because the sled was 8 feet long, the "front" of the sled (in the direction of movement) begins each length at the 8-foot mark. To calculate the extra distance covered during an incomplete length, operators recorded the final position of the front of the sled and subtracted its 8-foot starting position. The total distance recorded during the ICR task was: (number of full lengths x 12ft) + extra distance (ft) covered. As an example (**Figure 11**, below), if the subject covered 15 full lengths and the front of the sled was pulled to the 14-foot mark when time expired, the distance covered during the partial length would be 6 ft (14ft – 8ft), making the total distance covered 186 ft ([15 lengths x 12 ft] + 6 ft).

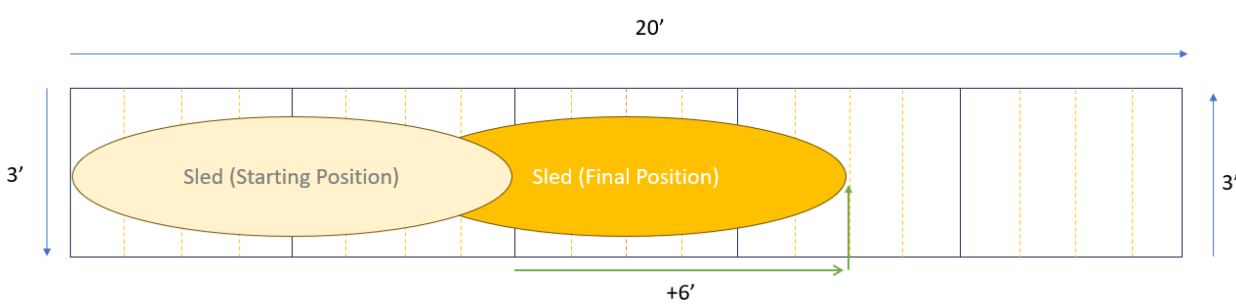



*Figure 11: Example scoring for incomplete length/lap during ICR task*

*Payload Transport:* Study operators recorded the full laps completed (1 lap = 46ft). If subject had an incomplete final lap during the 4-minute task period, the operators recorded the distance from the start of the lap to the end position. As an example (**Figure 12**, below), if the subject covered 20 full laps plus 17 ft of the next lap, the total distance covered was 937 ft ([20 laps x 46 ft] + 17 ft).

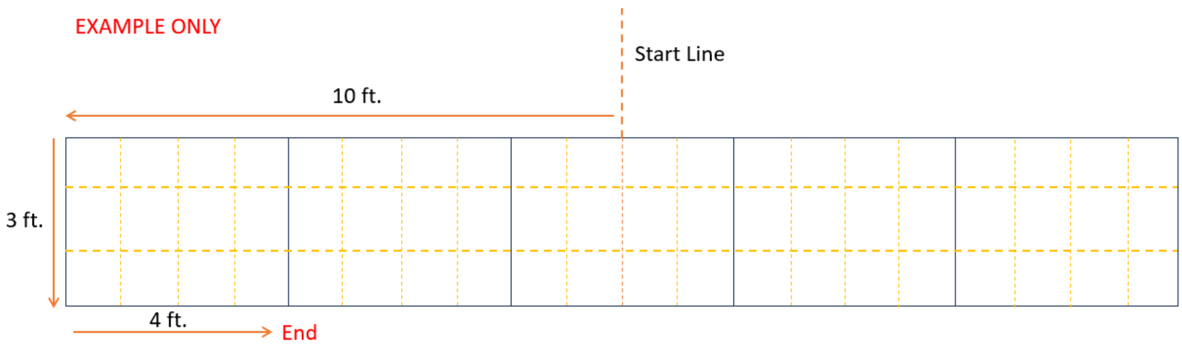



*Figure 12: Example scoring for incomplete lap during Payload Transport task*

*Prone Recovery:* Study operators recorded the number of complete repetitions (prone pushup position to fully standing).

*Traverse:* Study operators recorded the full laps completed (1 lap = 46ft). If subject had an incomplete final lap during the 4-minute task period, operators recorded the distance from the start of the lap to the end position. As an example (**Figure 13**, below), if the subject covered 20 full laps plus 35ft into the next lap, the total distance covered was 955 ft ([20 laps x 46ft] + 35ft).

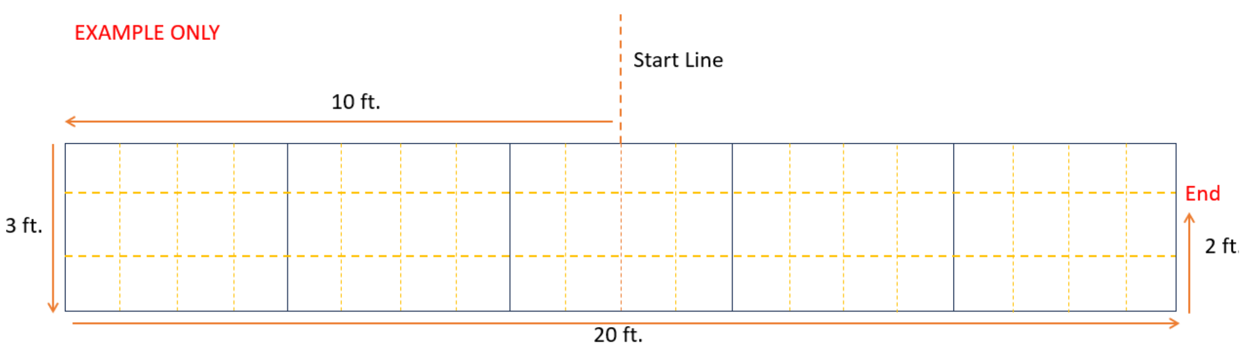



*Figure 13: Example scoring for incomplete lap during Traverse task*

## Pilot Study Methods

### *Study description*

Pilot testing (n=8; 50% female) was performed at NASA Johnson Space Center. Non-astronaut subjects, aimed to achieve "astronaut-like" demographics were recruited for this study. Specifically, individuals between the ages of 25 – 55 yrs and having a body mass index (BMI) between 18.5 – 29.9 kg/m$^2$ were recruited, with the aim of equal proportion of male to female subjects. Additional inclusion criteria are as follows: Subjects must have passed an Air Force Class III equivalent physical examination, which included a complete medical history, a vision and hearing test, a 12-lead resting electrocardiogram, with a blood and urine sample being collected by the Test Subject Screening (TSS) facility. Part of the examination included screening for the presence of illegal drugs, HIV, and Hepatitis B. Subjects were assessed through height and weight to ensure they were within the required range for body mass index. Exclusion criteria included taking psychotropics or prescription medication the control of chronic pain, resting blood pressures greater than 140mmhg/90mmhg (Systolic/diastolic), the use of beta blockers or diuretics, the presence of orthopedic injury or arthritis, or the implantation of orthopedic implant, cardiac pacemaker or other implanted electromedical device.

This study was approved by the NASA JSC Institutional Review Board and informed consent was given by all subjects. Participation in the study included a consent visit, 4 visits for aerobic and muscular fitness assessments, and final visit including a familiarization session and completion of the EVA task circuit assessment. Testing for this study took place from December 2024 through February 2025.

### *Fitness Assessment Selection*

A systematic review of literature was used to develop a list of candidate physical fitness assessments for inclusion in this study [16]. Assessments were selected to capture at least one fitness category: aerobic capacity, muscular strength, muscular power, and muscular endurance. The literature review identified 7 separate assessments that were measured in multiple studies which reported either performance thresholds or a significant association with EVA task performance, including $VO_{2pk}$ (treadmill and cycle), critical power (rowing), isometric and isotonic leg press, and isometric and isotonic bench press. Three assessments were identified by SMEs based on association with EVA task performance and ease of implementation including handgrip, 2-minute squats, and 2-minute pushups. Additional assessments were added based on potential operational needs/utility (walking economy, isometric midthigh pull), potential comparison to historical crew data sets (isokinetic strength and endurance), and validation of NASA-STD-3001 (1-RM bench press and deadlift). Cycle critical power was included due to relevance to potential exploration exercise capabilities, as well as relative safety and ease of administration. While arm crank critical power and treadmill critical speed were assessed in multiple previous studies [16] and demonstrated strong relationships to task performance, equipment availability and timing/safety considerations (overhead of additional assessments; treadmill running in a deconditioned and/or spaceflight population) removed these assessments from consideration.

### *Fitness Assessment Description*

Fitness assessments were performed over the course of 4 visits (**Figure 14**), with at least 48hr between visits to minimize the impacts of fatigue and soreness. Visits were designed to include both muscle and aerobic based assessments; given the amount of testing, assessments and timing were chosen based on balancing subject time and overall workload.

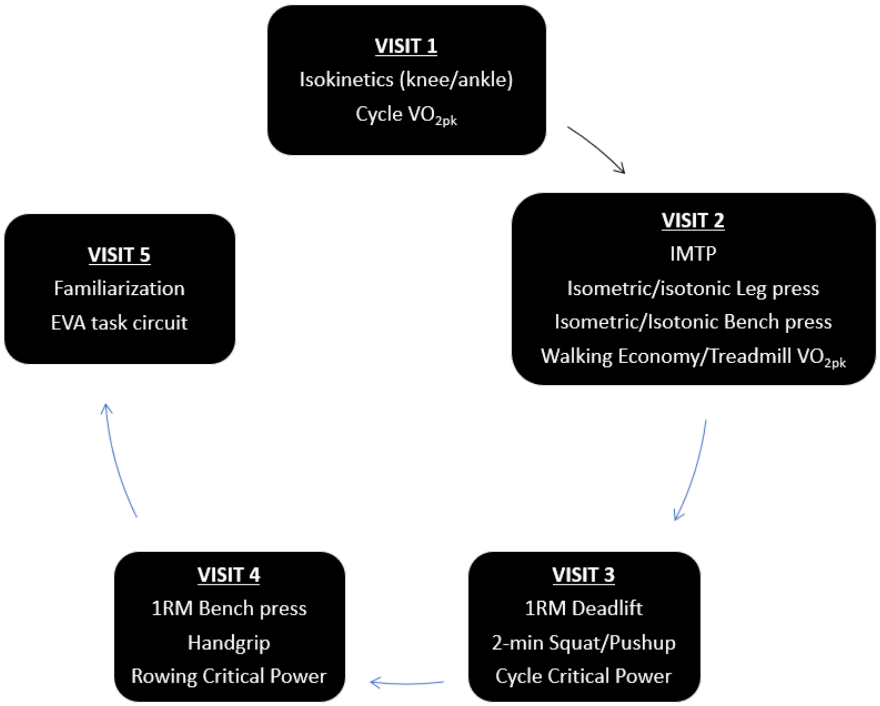



*Figure 14: POLAR study visits*

*Peak aerobic capacity, VO2pk; 1 repetition maximum, 1RM.*

Aerobic capacity, economy, and anaerobic power assessments:

Cycle $VO_{2pk}$: Subjects performed a graded exercise test on the cycle ergometer (Lode, Goningen, The Netherlands) to determine $VO_{2pk}$ and ventilatory thresholds (VT1 and VT2), while being continuously monitored using 12-lead ECG (CASE ECG System, General Electric Medical Systems Information Technologies, Milwaukee, WI, USA) and metabolic measurement system (TrueOne 2400; PARVO, Salt Lake City, Utah, USA). The graded exercise protocol has two versions (nominal or light [11, 22]), dependent on subject body weight (light protocol for subjects <60 kg). For the nominal protocol, subjects completed a warmup on the cycle ergometer for 3 minutes at 50W before starting the test which increased 25W each minute until volitional fatigue. For the light protocol, subjects completed a warmup on the cycle ergometer for 3 minutes at 45W before starting the test which increased 15W each minute until volitional fatigue. Rate of perceived exertion (RPE) was collected periodically as a subjective workload rating between 6-20 associated with designations of workload, and blood pressure was manually assessed before, during, and after test completion for monitoring purposes.

Walking economy (steady state metabolism): Subjects walked on the treadmill (GE T-2100 Treadmill, General Electric, Boston, MA, USA) while being continuously monitored using 12-lead ECG and metabolic measurement system. The test included 3 x 3-minute stages, at speeds of 1.2mph (stage 1; approximate assumed speed listed in exploration ConOps for traverse [7]), 2.5mph (stage 2), 3.0mph (stage 3). Walking steady state metabolism occurs after 2 minutes [23]; therefore, walking economy was determined as the highest $VO_2$ values during the last minute of each stage.

Treadmill $VO_{2pk}$: Subjects performed a graded exercise test [24] on the treadmill to determine $VO_{2pk}$ and ventilatory thresholds (VT1 and VT2), while being continuously monitored using 12-lead ECG and metabolic measurement system. Subjects started the test at constant walking speed of 3.3 mph and an incline of 0 percent. After 1 minute, the incline increased by 2 percent and every minute thereafter by 1 percent until the subject reached volitional fatigue.

Rate of perceived exertion (RPE) was collected periodically as a subjective workload rating between 6-20 associated with designations of workload, and blood pressure was manually assessed before, during, and after test completion for monitoring purposes.

Cycle Critical Power (CP): CP testing was completed on a cycle ergometer (Lode, Goningen, The Netherlands) using established procedures [25]. Subjects performed a 5-minute warmup on cycle ergometer at 100 watts with a self-selected cadence. After warmup, subjects completed 1 minute of unloaded cycling; during the last 5 seconds of warmup they were instructed to increase their cadence to 110 rpm. Subjects immediately proceeded to 3 minutes of "all-out" effort, where they were instructed to pedal as hard as they could throughout the entire 3 minutes of effort. No auditory cues of duration were provided by study team to avoid self-pacing strategies. The CP was calculated from the average power obtained over the last 30 seconds of the test (end power, EP). The anaerobic capacity was estimated through the work above end power (WEP) or the integral of the work performed under the time-power curve and above the EP line.

Rowing CP: Rowing CP assessment was adapted from established procedures [26]. Subjects performed a 5-minute warmup on rowing ergometer (Concept 2, Morrisville, VT, USA), between 50-100 watts at a stroke rate of 20-25 strokes per minute (spm). After the warmup, subjects rowed for 1 minute with the fan setting at the lowest setting (1 out of 10); during the last 5 seconds of this period, they were asked to increase stroke rate to maximum and the fan setting was increased to a 6 or 8 based on pre-determined body weight thresholds. Subjects immediately proceeded to the 3-minute all-out effort and were told to maintain their maximal stroke rate for 3 minutes without pacing. Similar to the cycling test, no auditory cues were given regarding the test duration. EP and WEP were processed using identical procedures to the cycle critical power assessment.

Muscle strength, endurance, power assessments:

Equipment: Isometric Midthigh pull (IMTP) and bench press assessments were performed on the FT700 Plyometric Power System (Fitness Technology, Skye, SA, Australia), with a position transducer (PT5A, Fitness Technology), magnetic braking system (Fitness Technology, Skye, SA, Australia), and 2 force plates (Type 9286, Kistler Instrument Corporation) to measure ground reaction forces during testing [27]. Leg press measurements were performed using a customized leg press machine (6000a Leg Press, Nebula Fitness Equipment, Versailles, OH), equipped with a force plate (Type 9281C, Kistler Instrument Corp., Amherst, NY, USA), position transducer (PT5A, Fitness Technology, Skye, SA, Australia), and magnetic braking system (Fitness Technology, Skye, SA, Australia). Force and position data was collected using data acquisition system (NI USB 6251 M Series Multifunction DAQ, National Instruments, Austin, TX, USA) and LabVIEW software (National Instruments). Force plates and position transducers were zeroed before each effort. Bench press and leg press assessments were performed using previously published methods [11, 27]. Prior to any strength assessments, subjects completed a 3–5 minute warm-up on a rowing ergometer (Concept 2, Morrisville, VT, USA).

IMTP: The subject was instructed on proper body position and overhand grip with wrist straps (Harbinger, Durham, NC, USA). Knee and hip joint angles were assessed via goniometer and body position was adjusted to aim for knee and hip angle ranges for this investigation were 125-145° and 140-150° respectively [28]. Three warm-up trials were performed at 50% maximum, 75% maximum, and near maximal effort to familiarize the subject with the movement and double check body positioning when applying force to the bar. The test consisted of 3 maximum effort attempts lasting for 3–5-seconds to see force curve plateau, with no less than 2 minutes of rest between attempts. Peak force was identified as the greatest force produced during each attempt, using 1000Hz sampling rates.

Isometric Leg press: For this assessment, the sled/force plate was positioned to create a 90° knee angle using an adjustable pin-stop. Three warm-up trials were performed at 50% maximum, 75% maximum, and near maximal effort each separated by 1 minute of rest between attempts. Three maximal efforts (3-5 seconds) were performed, separated by 2 minutes of rest between attempts. Force data was sampled at 1000 Hz and low-pass filtered at 4 Hz. Peak force was identified during each attempt.

Isotonic Leg Press: For this assessment, the mechanical pin-stops were disengaged to allow the sled/force plate to rest against lower safety stops that prevent the sled from moving to a position that would create a knee angle of less than 90°. The sled was loaded with free weights equal to 40% of the subject's maximal isometric force, as this load has previously been shown to elicit maximal power output and results in the greatest instantaneous power [27]. Subjects began the test with a 90° knee angle and then perform 21 consecutive concentric ballistic repetitions. A magnetic brake dampened the return load so that no eccentric muscle actions will be performed for injury prevention. Repetitions were performed without rest. Subjects performed each repetition as soon as the force plate has returned to the starting position. Force and position data were sampled at 300 Hz and low-pass filtered at 4 Hz. Peak instantaneous power (W) was determined from the single best attempt.

Isometric Bench Press: For this assessment, the bench press bar was placed on top of the adjustable safety stops provided by the manufacturer. The position of the stops was set so that the bar was as close to the subject's chest as possible without touching it and locked in place atop the safety stops using adjustable turnbuckles. Three warm-up trials were performed at 50% maximum, 75% maximum, and near maximal effort each separated by 1 minute of rest between attempts. Subjects performed three maximal efforts (3-5 seconds), separated by 2 minutes of rest. Force data was sampled at 1000 Hz and low-pass filtered at 4 Hz. MIF was identified during each attempt.

Isotonic Bench Press: For this assessment, the turnbuckle stops were removed to allow the bar to rest freely against the safety stops at the beginning of the test. The bar was loaded to 30% of the subject's MIF, a load that has been shown to elicit the highest instantaneous peak power [27]. Twenty-one consecutive maximal ballistic repetitions were performed without rest between repetitions. The magnetic brake was used to dampen the return velocity of the bar; and test operators returned the bar back into the starting position so that no eccentric muscle actions were performed. Force and position data were sampled at 300 Hz and low-pass filtered at 4 Hz. Peak instantaneous power (W) was determined from the single best attempt.

Isokinetic Knee (flexion and extension): For this assessment, subjects were seated and secured on an isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA). Subjects performed 3 warm-up concentric repetitions (extending and flexing knee) at an angular velocity of 60°/second, followed by a 2-minute break. Subjects then perform 5 maximal effort concentric repetitions at an angular velocity of 60°/second, with peak torque (Nm) identified.

Isokinetic Ankle (flexion and extension): For this assessment, subjects were seated and secured on an isokinetic dynamometer. Subjects performed 3 warm-up concentric repetitions (extending and flexing ankle) at an angular velocity of 30°/second, followed by a 2-minute break. Subjects then performed 5 maximal effort concentric repetitions at an angular velocity of 30°/second, with peak torque (Nm) identified.

Handgrip strength: All subjects completed test in a standardized testing position, such that subject seated comfortably in chair with back support and arm flexed at 90°angle with forearm in neutral position [29, 30]. Grip position was adjusted to the subject's hand size. Subjects performed a maximal effort handgrip attempt, squeezing the hand dynamometer (Jamar, Sammons Preston, Rolyon, Bolingbrook, IL, USA) for 3 seconds before resting for 1 minute. This process was repeated until 3 attempts were completed on both dominant and non-dominant hands. The peak measurements from the three trials on each hand were reported.

1-Repetition Maximum (RM) Deadlift and 1-RM Bench press: Prior to assessment, subjects completed a brief familiarization session where they were instructed on and practiced proper form (unweighted) and then completed a dynamic warmup of 10-15 stretches/body movements. For this assessment, subjects followed a standardized protocol [31]. Three warmup sets with light resistance for 8-10 repetitions (target intensity 50-65% of expected max), set 2 with increased weight (to for 4-6 repetitions (target intensity 65-75% of expected max), and set 3 with increased weight for 2-3 repetitions (target 80-85% of expected max); each set with 1-3 minutes rest. After warm-up sets, up to 5 attempts were completed by adding 5-10% weight until the subject could no longer complete 1 repetition with the prescribed weight, with 3 minutes rest between attempts. 1-RM Deadlift and bench press were performed on different days with at least 48hr between sessions.

2-minute squat: Proper body weight squat form was demonstrated prior to testing. The subject was positioned in squat rack with an exercise band (with bell) at a height adjusted to achieve 90° knee flexion, confirmed with goniometer. When the subject was ready, they completed as many squats (descending to 90°flexion as indicated by glutes touching the exercise band with an audible ring of bell) as possible in a 2-minute period.

2-minute pushup: Proper hand-release pushup form was demonstrated prior to testing. Starting with hands slightly wider than shoulder-width and elbows positioned at 45°angle, subjects pushed to extend elbows to elevate entire body from the ground, maintaining straight body alignment. Subjects then returned to the ground, briefly released hands from the ground and fully extend both arms laterally into a “T” position, before returning hands to the ground. When the subject was ready, they completed as many hand-release pushups as possible in a 2-minute period. Pushups with improper form (fail to maintain generally straight body alignment, sagging at hips/knees, failure to extend arms into T or failure to return to starting position) were not counted.

### *EVA Task Circuit Description*

EVA Task circuit Assessment (previously described): During the final visit of the study (**Figure 14**), subjects completed a short familiarization session to cover task circuit instructions and demonstrate proper form for each task. Subject wore weights applied to body (total weight 50.4lb to include weighted vest, waist weight, wrist, ankle and foot weights applied to each arm and leg) to approximate the Lunar mass of a spacesuit. Additionally, subjects wore portable metabolic gas analyzer (K5, COSMED, Rome, Italy) and heart rate monitor (POLAR, Kempele, Finland) for continuous monitoring throughout the task circuit. Subjects completed the following tasks within ~17 minutes:

- Incapacitated crew rescue: 4 minutes of dragging a rescue sled with 110lb resting on top, across a designated path
- Payload transport: 2 minutes of walking laps around designated path, carrying two 30lb sandbags
- Prone Recovery: from supine position, pushing up to a standing position, then repeating for 30 seconds
- Traverse: 4 minutes of walking laps around designed path at self-selected pace

Metabolic rate and heart rate during each task was determined though 30 second averaging and effort during the tasks was presented as percentage of cycle $VO_{2pk}$ or percentage of heart rate maximum (achieved during cycle $VO_{2pk}$ testing).

The following constraints were followed for exercise and EVA task circuit assessments: No maximal exercise 24 hours prior to testing; no exercise 8 hours prior to testing; limit caffeine intake 8 hours prior to testing; no alcohol or nicotine 8 hours prior to testing.

## Discussion

The POLAR Project was designed as a preliminary investigation to identify and test fitness parameters that may best inform EVA task performance for the refinement of the NASA-STD-3001 for aerobic capacity and muscle strength. This 3-part effort included a systematic review of literature [16], a task analysis to select critical and physically demanding EVA task from exploration ConOps for the development of an Artemis-relevant EVA task circuit, and the pilot testing of identified fitness metrics in conjunction with novel task circuit performance. Together, the results from this project can be used as the initial step to the ongoing refinement of NASA standards, laying the foundation to explore the fitness and performance relationships at a larger scale in future research investigations.

Ultimately, the NASA-STD-3001 should be based on the minimum requirements necessary to perform EVA and spaceflight-related tasks. From a surface EVA perspective, the only previous experience performing tasks on a planetary surface occurred during Apollo missions, in a time when astronaut fitness assessments were not standardized and quantification of EVA performance was not specified. Despite the many lessons learned from Apollo missions, mission parameters were distinctly different than what is being planned for Artemis missions including increased frequency of EVAs (up to 5 in one week for Artemis [6, 7] vs up to 3 per mission in Apollo [32]), increased duration of up to 8 hr [6, 7] (vs Apollo maximum duration 7.5hr [5]), and be performed in a spacesuit nearly double in weight (91-96 kg for Apollo [8] vs ~182 kg in Artemis [9]). Therefore, determining “minimum requirements” for exploration activities remains a challenging endeavor, which will likely be iterated with the collection of new data from terrestrial studies, analog experience, and eventually, actual surface operations.

This project incorporates methodologies utilized in other occupations that have higher physical demand and are typically incorporated in the development of physical employment standards (PES) [15]. In the context of NASA and spaceflight, fitness standards are ***not*** employment standards – selection criteria (and subsequent flight assignment) for astronauts goes beyond fitness and is a multifactorial selection process which includes achieving a certain level of education in STEM field, specific length of professional experience, and evaluations for health, leadership, teamwork, and communications. As such, it would be inappropriate to suggest that employment is contingent on the ability to meet fitness standards. However, this project utilized a modified PES framework to systematically identify key EVA tasks relevant to Artemis Lunar missions, as outlined in exploration ConOps documentation.

Few institutions are equipped to provide higher fidelity EVA simulation capabilities (e.g., off-loading/suited capabilities, authentic tools/equipment, etc.) which has driven previous investigations from Ryder et al [11, 12] and others [16] to leverage EVA task circuits to assess fitness and EVA task performance. Different approaches and methodologies employed by these researchers make it difficult to consolidate findings into succinct and targeted recommendations [16] to inform fitness standards. Therefore, the POLAR project attempts to bridge this gap, through an Artemis EVA-focused task circuit designed as a "standardized" approach for increased utility in a variety of testing environments, with transportable equipment and short-duration efforts. It is the hope that the task circuit can be utilized by researchers internal and external to NASA to apply consistent methodology help build more evidence to further refine the NASA-STD-3001 fitness standards for exploration EVAs. Forward work is needed to determine the psychometric properties (reliability and construct validity [33]) of the POLAR task circuit.

# Acknowledgments

This project could not have been completed without the diligent and intensive work of team members within the Exercise Physiology and Countermeasures Laboratory (Sarah Browning, Dana Gardner, Lori Cooper, and Kate Caughlin) and EVA & Environmental Physiology Laboratory (Patrick Estep, Zach Wusk, Madison Herrmann). Special thanks to the SERPO community for contributing to the task analysis/survey. Finally, to the subjects- your enduring effort for this involved study is helping to better NASA's mission.

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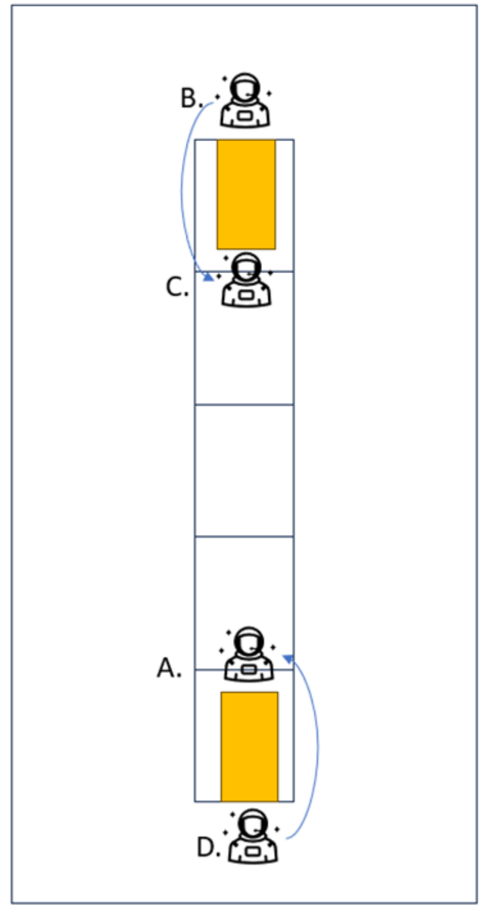
# Appendices

## Appendix A: Diagrams for Task Circuit Tasks

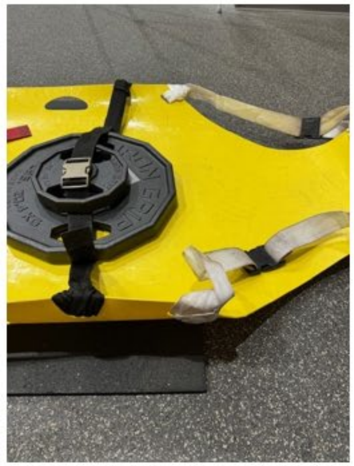
### Incapacitated Crew Rescue

<table>
<tr><th></th><th colspan="2"></th></tr>
<tr><td>Protocol:</td><td colspan="2">1. Subject starts in position A. facing the sled, drags sled to position B.<br>2. Subject drops handle and walks to position C.<br>3. Subject picks up handle and drags sled to position D.<br>4. Subject drops handle and returns to position A.<br>Note: Marked portion of sled must touch far ends of mat on each lap</td></tr>
<tr><td>Equipment:</td><td colspan="2">5 x (3x4’ rubber mats)<br>Sled<br>2 x 45lb plates<br>2 x 10lb plates<br>Tape<br>Timer<br>Subject: Foot, ankle, waist, wrist, chest weights</td></tr>
<tr><td rowspan="2">Operators:</td><td>Lead</td><td>Support</td></tr>
<tr><td>Ensures adherence to protocol/timing<br>Monitors subject</td><td>Assists with equipment<br>Measures final distance</td></tr>
<tr><td>Duration:</td><td colspan="2">4 min</td></tr>
<tr><td>Rationale:</td><td colspan="2">• 4 minutes of sustained intense movement is sufficient to stress aerobic capacity<br>• 110 lbs is representative of 99th percentile suited crewmember at Lunar gravity</td></tr>
<tr><td>Dependent Variable:</td><td colspan="2">• Distance sled covers</td></tr>
</table>

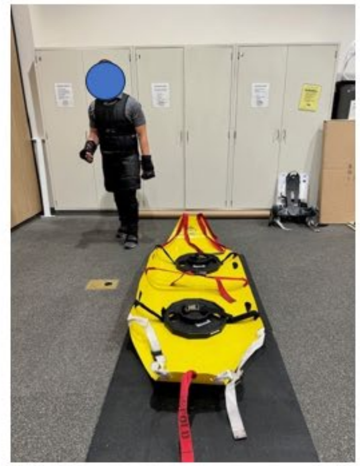


# Incapacitated Crew Rescue

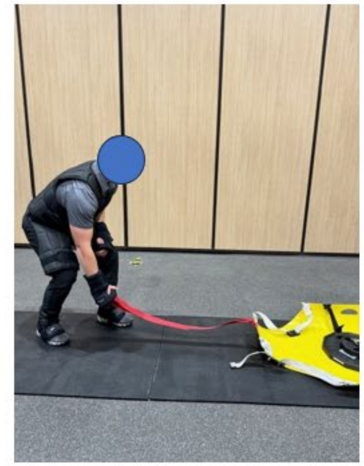
Subject pulls sled from start position to opposite end of the track



Subject pulls sled until ‘shoulder straps’ pass edge of mat



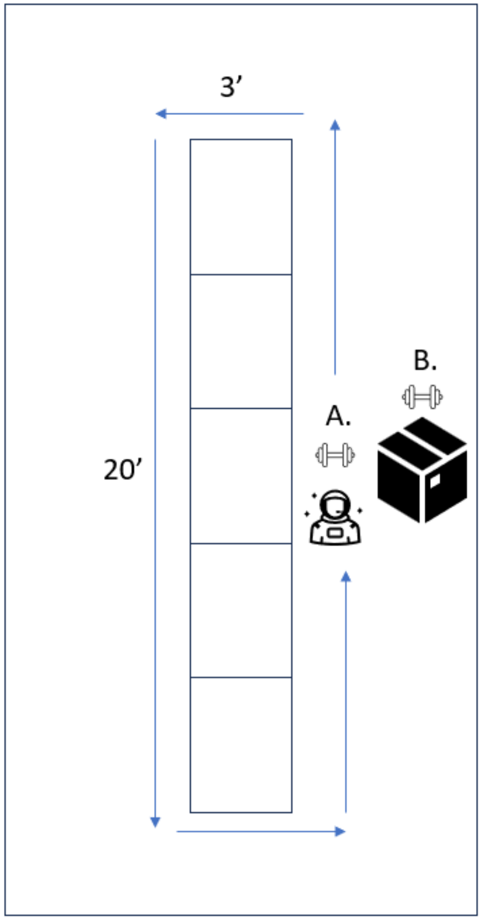
Subject walks around sled to reposition for walk back



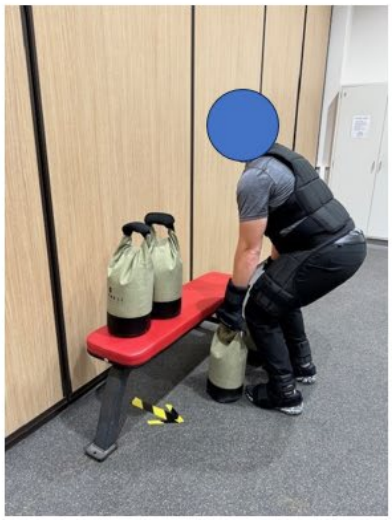
Subject grabs strap and drags sled in reverse direction

# Payload Transport

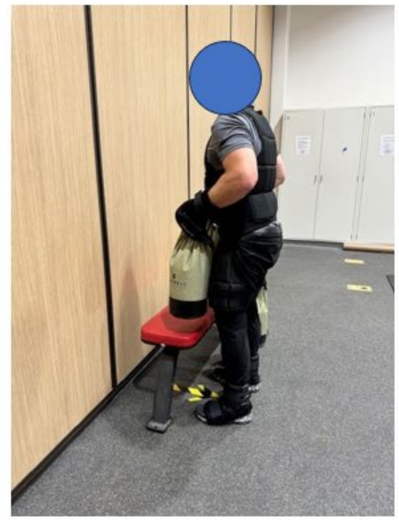
| | | |
|---|---|---|
| Protocol: | 1. Subject starts in position A picks up sandbags (2; one in each hand) from designated spot on the floor<br>2. Subject walks around the perimeter of the mats to complete a lap<br>3. Upon returning to position A, subject places sandbags back in position A<br>4. Subject grabs sandbags from on top of box at position B and completes a lap<br>5. Upon return to position B subject places sandbags on top of box and grabs sandbags from position A<br>6. Repeat steps 1-5 | |
| Equipment: | 5 x (3x4' rubber mats)<br>4 x 30 lb sandbag/kettlebells<br>Tapemeasure<br>Timer<br>Bench/Box<br>Subject: Foot, ankle, waist, wrist, chest weights | |
| Operators: | **Lead** | **Support** |
| | Ensures adherence to protocol/timing<br>Monitors subject | Assists with equipment<br>Measures final distance |
| Duration: | 4 min | |
| Rationale: | • 4 minutes of sustained intense movement is sufficient to stress aerobic capacity<br>• Astronauts will need to load and unload scientific/maintenance equipment, probably at various heights while maintaining a safe lifting movement | |
| Dependent Variable | • Distance traversed | |



# Payload Transport



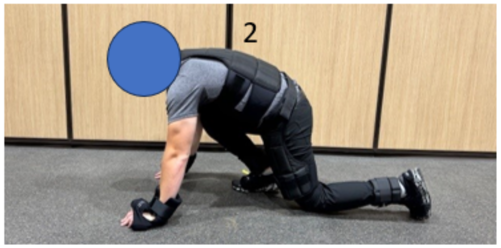
A. Sandbag ground position

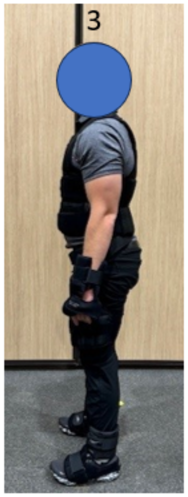


B. Sandbag elevated position

# Prone Recovery

| | |
|---|---|
| Protocol: | 1. Subject begins in prone position with hands at level of chest<br>2. Subject performs pushup like motion and slides foot up to about waist height<br>3. Subject stands fully upright [Count as 1 Rep]<br>4. Subject returns to prone position<br>5. Repeat steps 1-4 |
| Equipment: | 5 x (3x4’ rubber mats)<br>Timer<br>Subject: Foot, ankle, waist, wrist, chest weights |
| Operators: | **Lead**: Ensures adherence to protocol/timing<br>Monitors subject<br>**Support**: Assists with equipment<br>Counts repetitions completed |
| Duration: | 30 seconds |
| Rationale: | • Astronauts return to standing position after falling over<br>• 30s of effort will allow for maximal power generation while simultaneously assessing ability to repeatedly correct posture |
| Dependent Variable | • # of complete reps (measured at standing) |

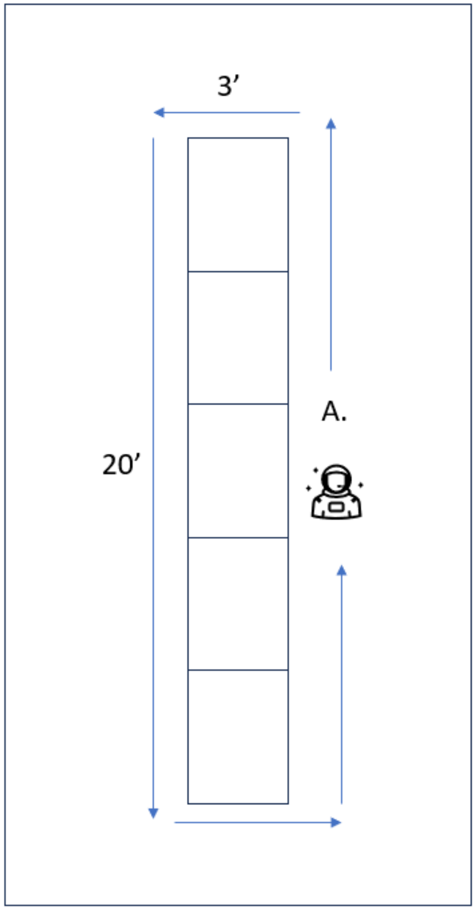




✓ A complete rep is counted upon fully standing to peak height

# Traverse

| | |
|---|---|
| Protocol: | 1. Subject starts in position A and upon starting signal, walks around perimeter of mats<br><br>* Subject must maintain walking motion (i.e., 1 foot on the ground at any point) |
| Equipment: | 5 x (3x4' rubber mats)<br>Timer<br>Tapemeasure<br>Subject: Foot, ankle, waist, wrist, chest weights |
| Operators: | **Lead**<br>Ensures adherence to protocol/timing<br>Monitors subject<br><br>**Support**<br>Assists with equipment<br>Measures final distance |
| Duration: | 4 min |
| Rationale: | • 4 minutes of sustained intense movement is sufficient to stress aerobic capacity<br>• Astronauts will need to traverse varied distances in order to complete mission objectives<br>• Without the ability to simulate a gradient (more stressful) placing the traverse at the end of the circuit will stress fatigue resistance carried over from previous tests |
| Dependent Variable | • Distance traversed |



**Appendix B: Equipment**

# Equipment

| Item | Qty. | Manufacturer | Image |
|---|---|---|---|
| 3x4' rubber mat | 5 | Unbranded; Tractor Supply Co. | A |
| Crew Rescue Sled | 1 | Skedco | B |
| 45 lb plates | 2 | Iron Grip | C |
| 30 lb Sand-bag (kettlebell) | 4 | Exerbell | D |

A

B

C


D

| Item | Quantity | Manufacturer | Image |
|---|---|---|---|
| 20 lb Weight Vest | 2 | Ironwear | E |
| 2.78 lb Ankle weights | 1 [ set of L/R] | Ironwear | F |
| 1.75 lb Shoe weights | 1 [ set of L/R] | Ironwear | G |
| 5.22 lb Wrist weights | 1 [ set of L/R] | Ironwear | H |

E

F

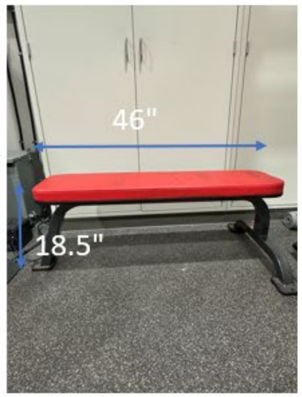
G

H

| Item | Quantity | Manufacturer | Image |
| --- | --- | --- | --- |
| 10.90 lb Waist weight | 1 | Ironwear | I |
| Bench | 1 | Quantum Fitness Corp. | J |
| Timer | 1 | Gan Xin | K |
| 10 lb plates | 2 | Iron Grip | L |

I

J




K

L