Predicting spaceflight operational performance from sensorimotor assessment tasks

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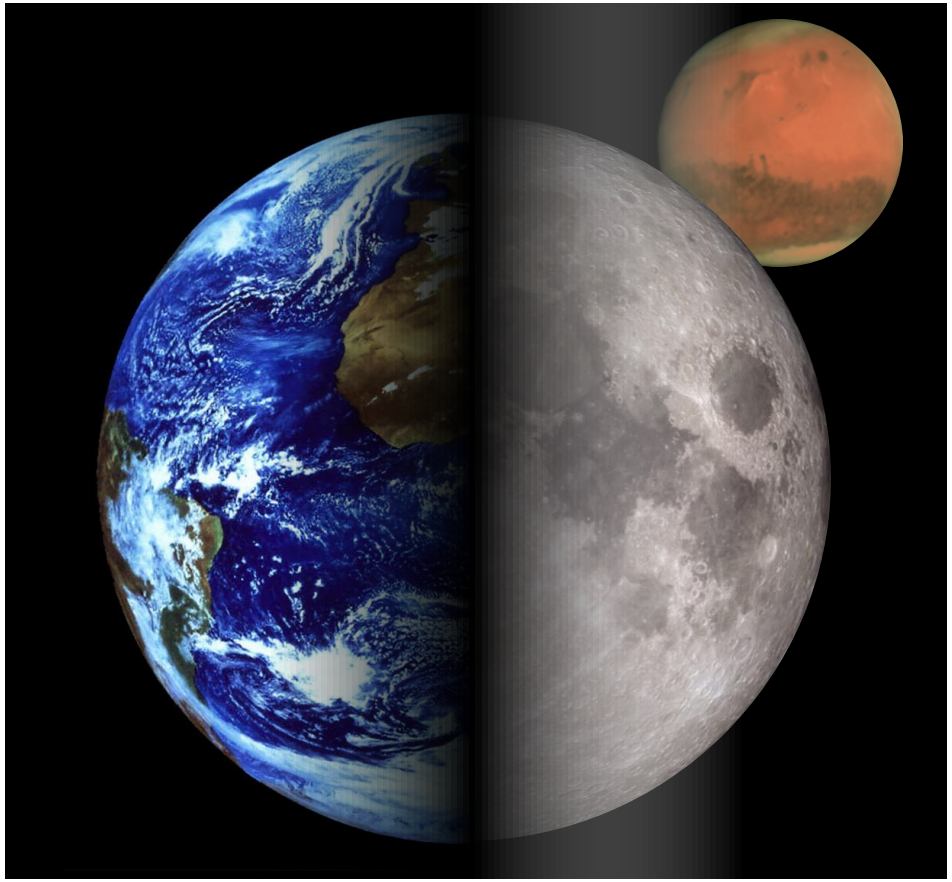

Background

- A new level of crew autonomy will be required for exploration class missions to self-assess and treat their sensorimotor dysfunction.
- Sensorimotor disorientation is at its highest around periods of gravitational transition (e.g., landing on the lunar/Martian surface).
- There is a need to define sensorimotor assessment tasks that indicate when performance in early extravehicular activities (EVAs) might be impacted or unsafe.

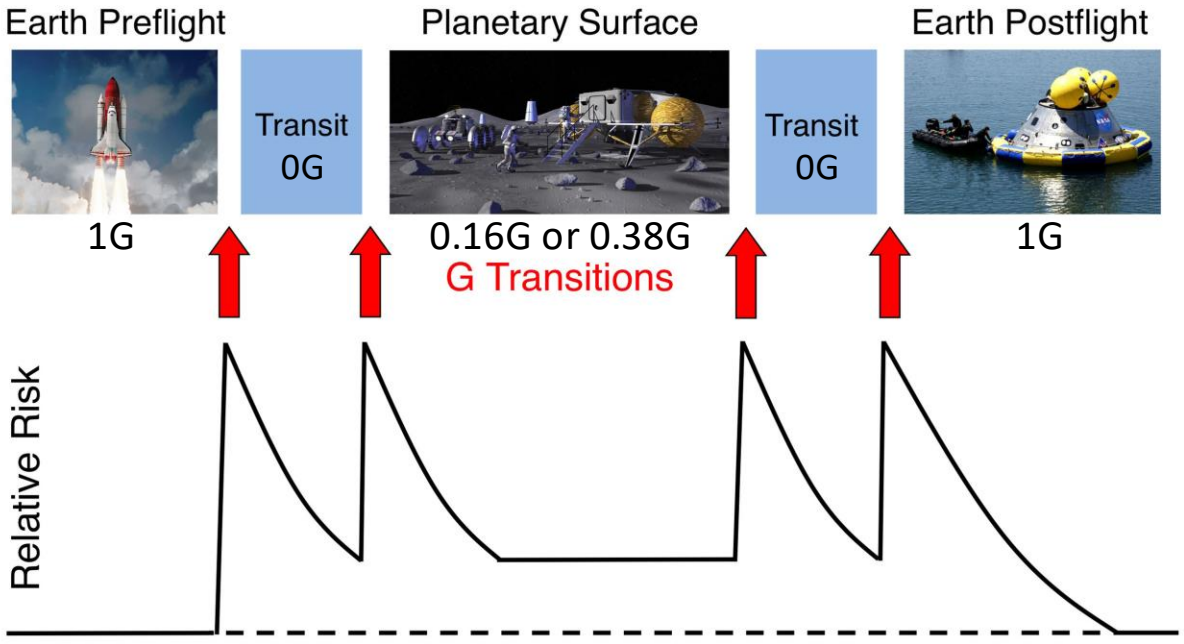

Figure adapted from Clement et al. 2022
Photos credit NASA

Background

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- There is a need to define sensorimotor assessment tasks that indicate when performance in early extravehicular activities (EVAs) might be impacted or unsafe.

To validate and down select a set of sensorimotor assessment tasks as determined by:

- Sensitivity to changes in sensorimotor disruption
- Ability to predict performance in operational analog task

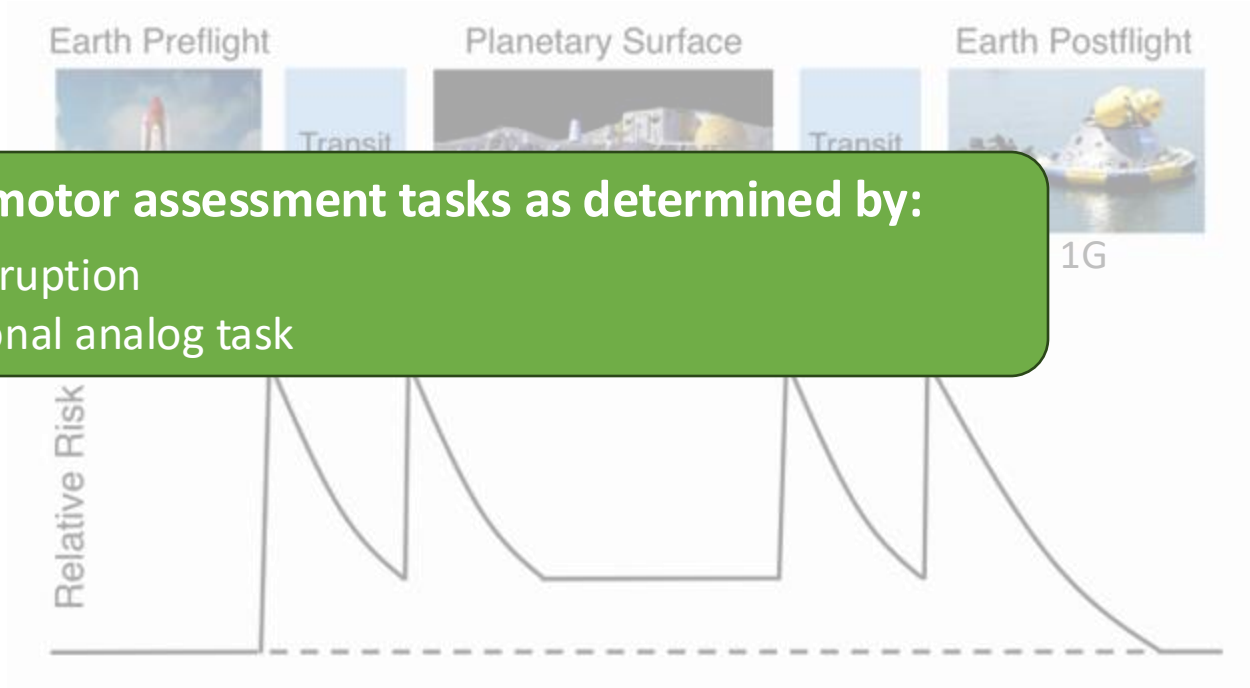


Figure adapted from Clement et al. 2022
Photos credit NASA

Methods

Developed a Sensorimotor Disorientation Analog (SDA) that simulates the effects of readaptation to a gravitational environment after a prolonged period in microgravity(Moudy et al., 2024)

Sensorimotor Disorientation Analog

Contains:

Galvanic Vestibular Stimulation

Weighted Suit

Mimics:

Astronaut postflight performance at

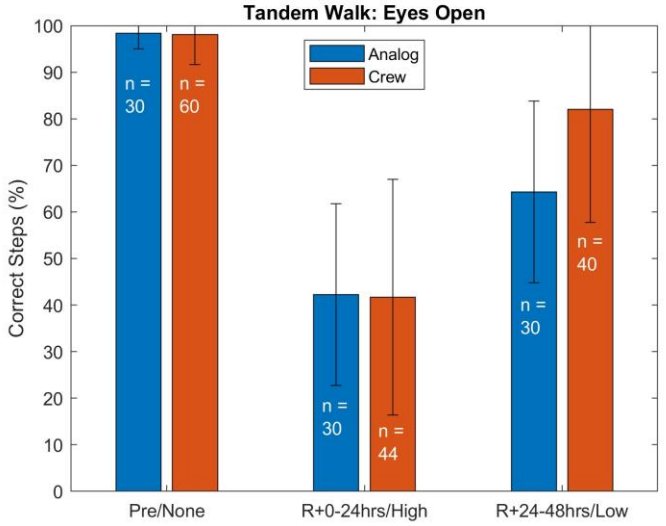
R+0-4 hours

R+24-48 hours

TABLE 2 Percent correct steps for tandem walk with eyes open and closed while wearing the Sensorimotor Disorientation Analog (SDA) at the high and low levels and postflight data retrieved from Clement et al. (2022) at the R+0 and R+1 time points.

	High Level/R+0		Low Level/R+1	
	Eyes open (%)	Eyes closed (%)	Eyes open (%)	Eyes closed (%)
SDA (R+0: n = 4, R+1: n = 5) (Mean, [Min, Max])	53.3 [18–75]	7.6 [0–19]	74.4 [56–100]	18.8 [12–30]
Clement et al. (2022) (n = 19) (Mean, [Min, Max])	33.5 [0–100]	9.9 [0–33]	84.6 [9–100]	25.3 [0–58]

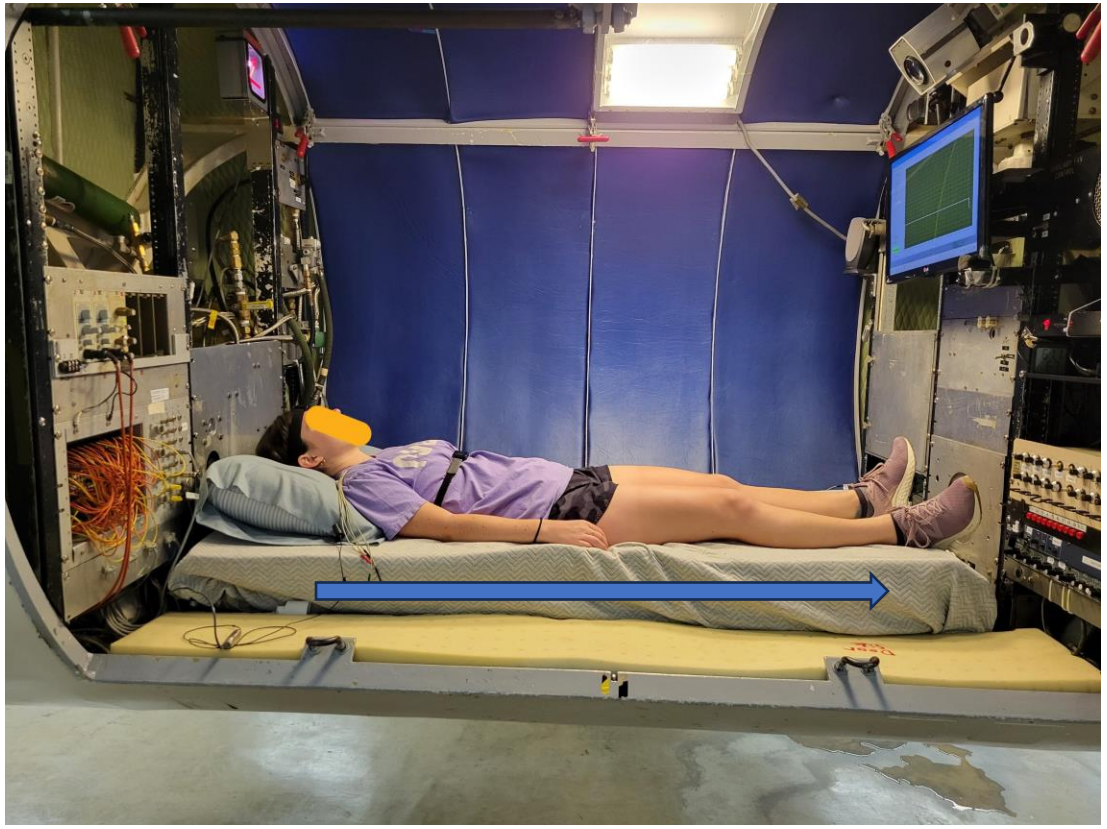
Clement et al. (2022) data retrieved from supplementary file. Average of the mean data for repeat and first flight was used.



All analog levels were significantly different from each other (p<0.001)

Methods

Sustained 60-min +3G_x centrifugation has been used in previous studies to mimic spaceflight motion sickness and postflight postural instability (Groen et al. 2008, Nooij et al. 2007)

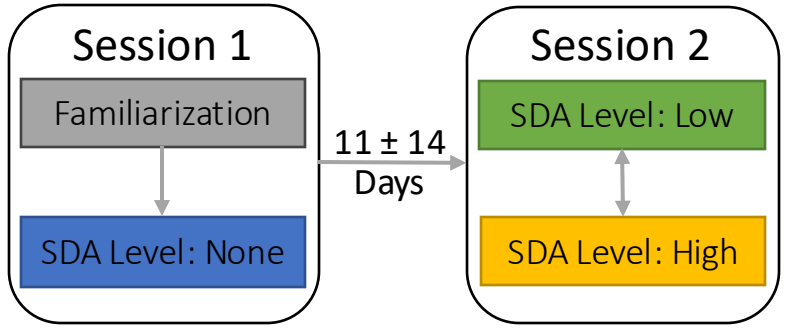


Methods

Sensorimotor Disorientation Analog

- 41 subjects participated in two sessions

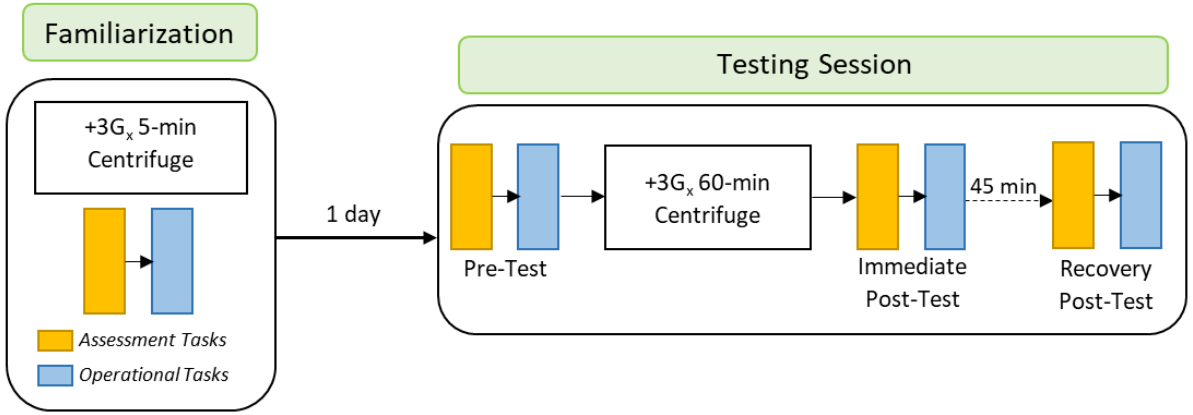
Age (years)	Height (in)	Weight (lbs)	Women/ Men	Low-High / High-Low
34.0 ± 7.8	68.5 ± 3.4	166 ± 29	20/21	20/21



+3Gx Centrifugation

- 16 subjects participated in two sessions

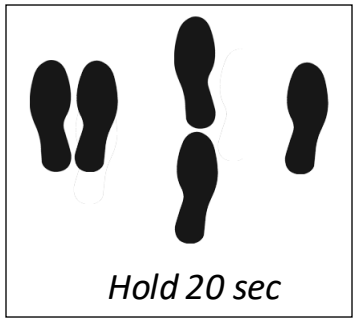
Age (years)	Height (in)	Weight (lbs)	Women/ Men
35.0 ± 9.5	67.1 ± 2.7	172 ± 26	6/10



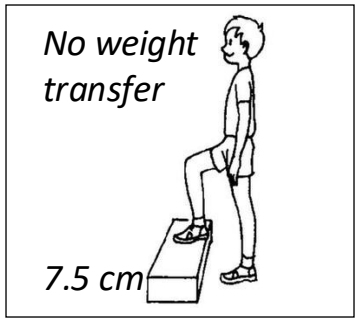
Methods

Sensorimotor Assessment Tasks

1. Postural Challenge

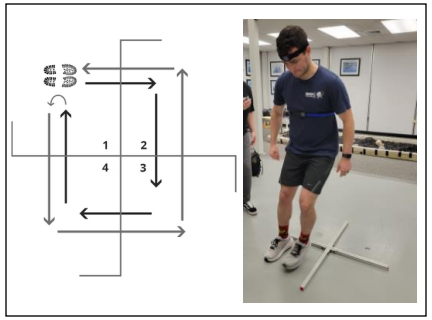


2. Step Test



3. Fall Recovery

4. Four-Square Step Test



5. Obstacle Turn

6. Kneel-and-Turn

Tap front & sides furthest ROM

Operational Analog Tasks

1. Capsule Egress

2. EVA Traversal

Results

- Moderate-to-strong correlations were present *between assessment tasks*:
  - SDA: $0.59 \leq r \leq 0.84$
  - Centrifuge: $0.38 \leq r \leq 0.91$
- The strongest *r*-values were between the two fall recovery options
- **Conclusion:** Task set could be reduced as performance in a subset of assessment tasks may adequately estimate performance across the full assessment set.

Results

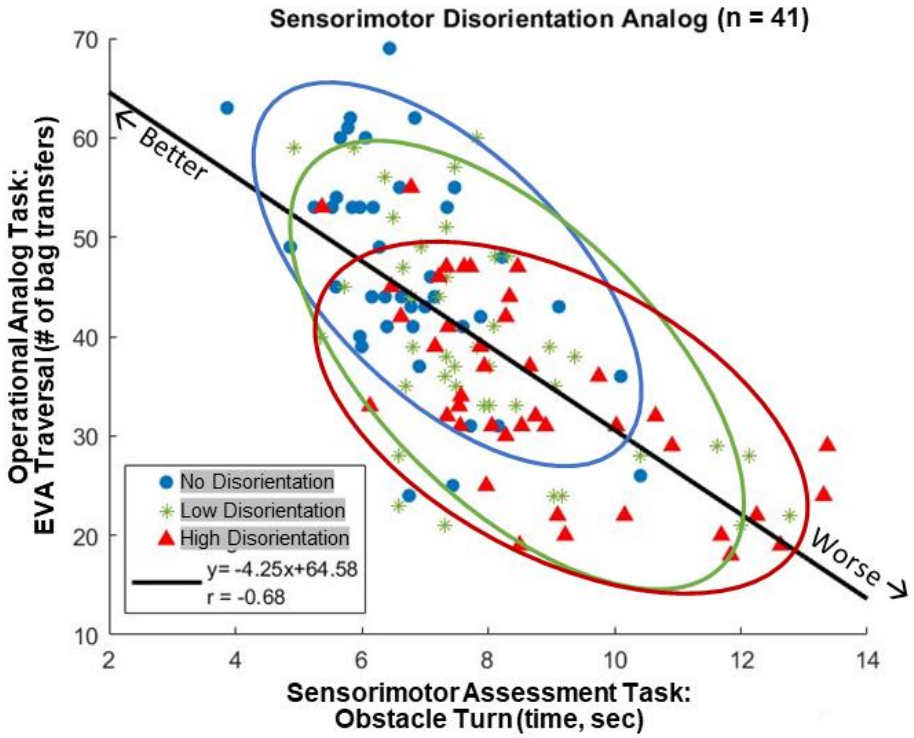
To determine the *predictive ability* of the assessment tasks, a series of tests were conducted starting with simple correlations between assessment and operational analog tasks:

- Capsule Egress:
  - SDA: $0.34 \leq r \leq 0.60$
  - Centrifuge: $0.21 \leq r \leq 0.69$
- EVA Traversal:
  - SDA: $0.53 \leq r \leq 0.68$
  - Centrifuge: $0.2 \leq r \leq 0.64$
- The step test consistently had the weakest correlations across disorientation paradigms and operational analog tasks
- The strongest correlations were with the obstacle turn task (SDA) and four-square-step-test (centrifuge)

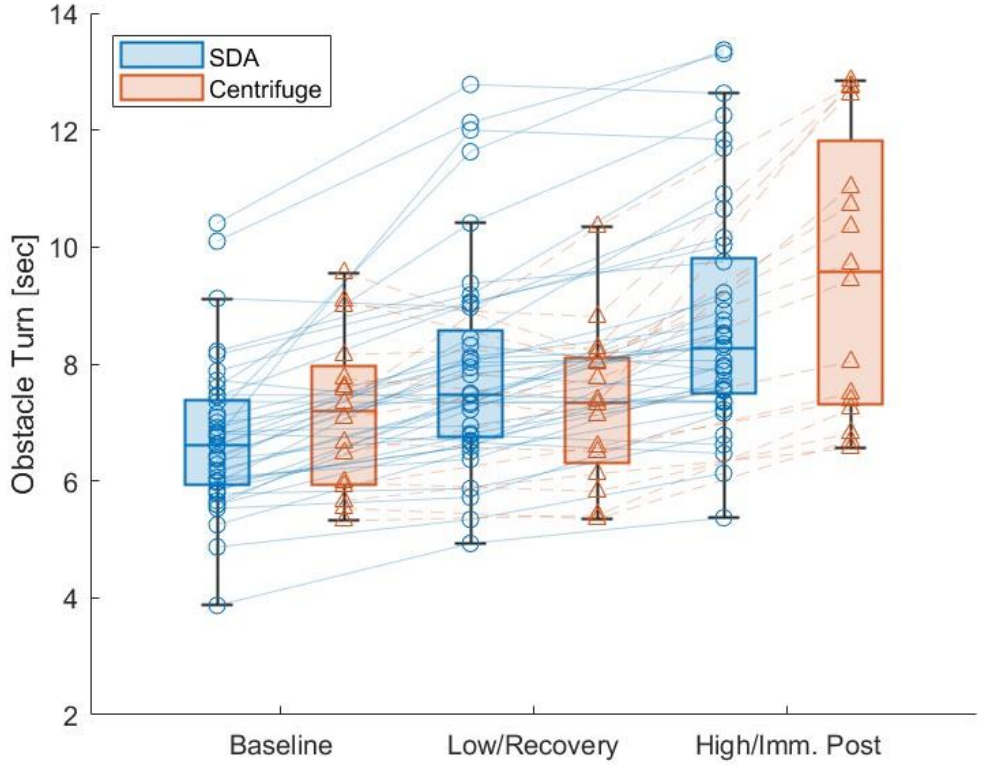
Simple correlations do not indicate predictive capabilities and only considers a single assessment task

Results

The predictions must account for the impact of sensorimotor impairment and inter-individual performance variability



Overlapping ellipses demonstrate the large performance variability independent of the disorientation level.

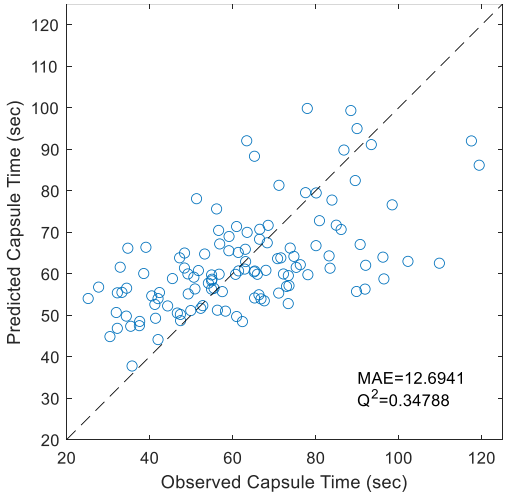


As disorientation levels ↑, some subjects improved performance:

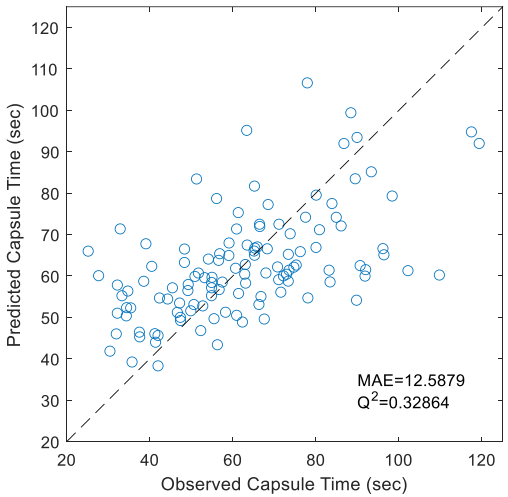
- Baseline → Low/Recovery: 4 for SDA and 8 for Centrifuge
- Low/Recovery → High/Imm. Post: 7 for SDA and 0 for Centrifuge

Results

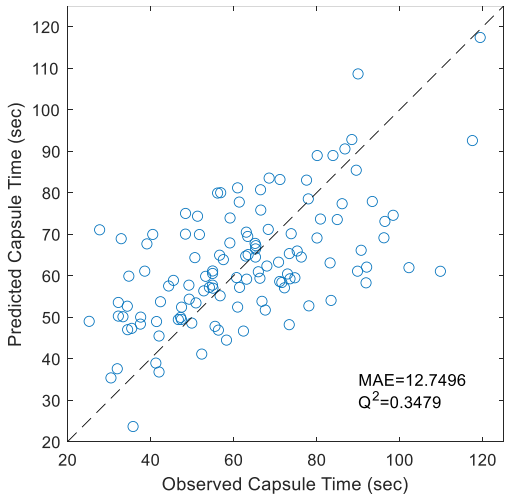
"Leave one out" cross-validation (LOOCV) conducted using these models to fit and predict the unseen observation using only assessment task performance as the predictor:



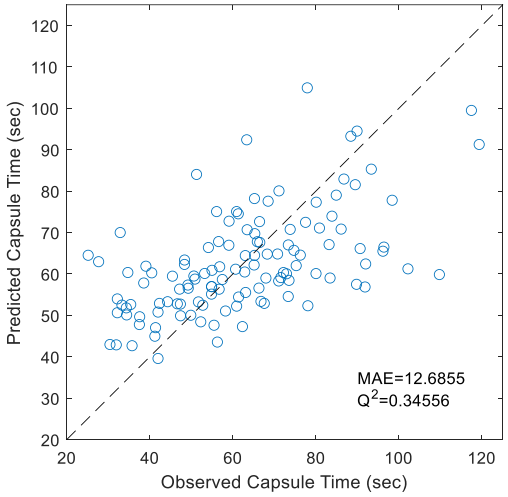
1. Simple linear regression using the assessment task with highest correlation to the operational analog task



2. Multiple linear regression seeded with all assessment tasks



3. Stepwise regression seeded with all assessment tasks



4. Multiple linear regression seeded with the principal axes from a principal component analysis of all assessment tasks

Results

	Sensorimotor Disorientation Analog (SDA)				+3Gx Centrifugation			
	Capsule Egress (sec)		EVA Traversal (# bags)		Capsule Egress (sec)		EVA Traversal (# bags)	
	MAE	Q^2	MAE	Q^2	MAE	Q^2	MAE	Q^2
Linear Regression with Strongest Correlated*	12.694	0.348	6.926	0.456	8.332	0.460	5.619	0.372
Multiple Linear Regression	12.588	0.329	6.988	0.487	7.809	0.446	6.123	0.201
Stepwise Linear Regression**	12.750	0.348	6.526	0.532	7.761	0.511	5.945	0.206
Linear Regression with PCA	12.686	0.346	6.755	0.499	9.351	0.251	5.805	0.266

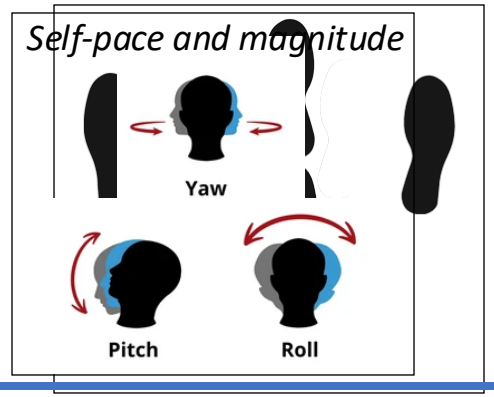
*SDA = Obstacle Turn Task (OTT), Centrifuge = Four-Square-Step-Test (FSST)

**SDA - Capsule Egress: Fall Recovery (prone & supine), OTT, Kneel-and-Turn (KTT)
SDA - EVA Traversal: Fall Recovery (prone), FSST, OTT
Centrifuge - Capsule Egress: FSST
Centrifuge - EVA Traversal: FSST, Fall Recovery (supine), KTT

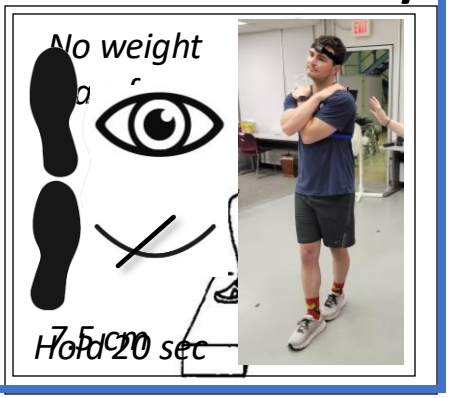
Conclusion

Sensorimotor Assessment Tasks

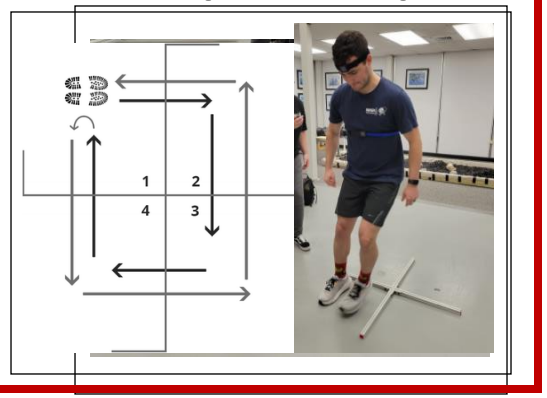
1. Head Motion Sensitivity



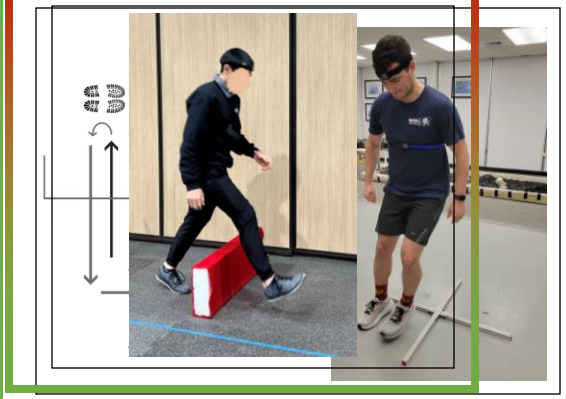
2. Postural Stability



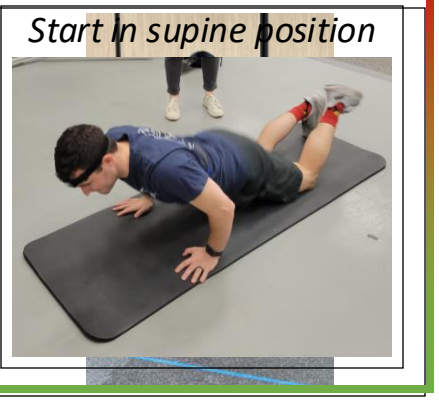
3. Four-Square Step Test



4. Obstacle Turn



5. Fall Recovery



6. Kneel and Turn

Blue = progressive adaptation; Red = sensorimotor validation; Green = mimic EVA body mechanics

Conclusion

- Next steps:
  - Define performance thresholds that would indicate when operational performance may be impacted or unsafe using 1g ground analog data
    - Parabolic flight is needed to define partial gravity performance thresholds
  - The task set is included in the “Artemis Lunar Lander & Egress” study

Thank You!

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