The diversity of adaptative responses following g-transitions during spaceflight

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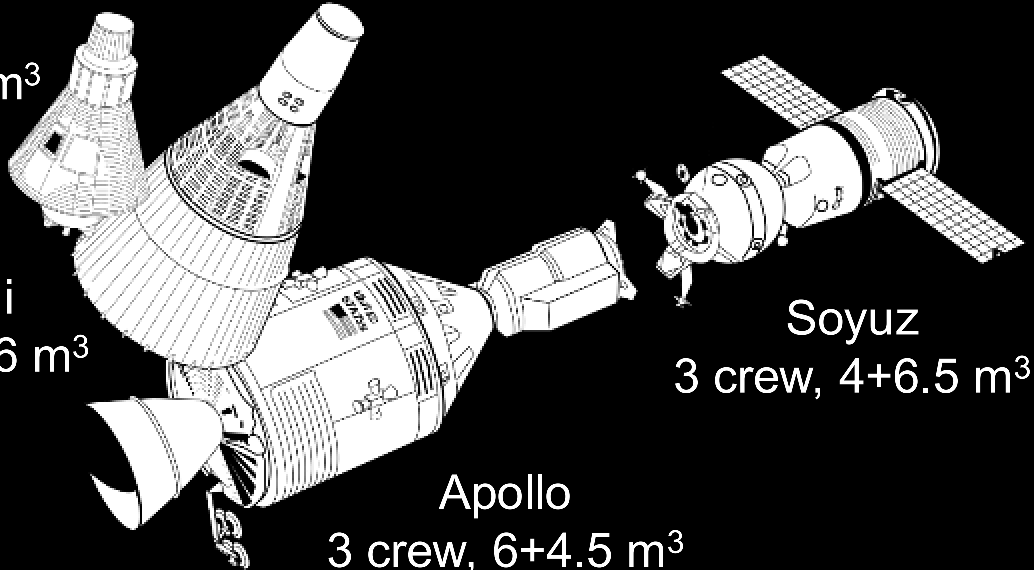
Adaptation to altered gravity states

- The need to move and maintain awareness of spatial orientation in altered gravity environment drives sensorimotor adaptation and learning to acquire a new set of synergies optimized for the novel environment.
- The perceptual and motor coordination problems experienced postflight reflect the recalibration of predicted versus actual movement feedback that is required for readaptation back to the natural gravitational state.

Inflight space motion sickness prevalence

- Prevalence has varied with spacecraft volume:
  - No SMS reported in Mercury or Gemini programs
  - 33% prevalence in Apollo (Homick 1975), 54% in Soyuz (Bryanov et al. 1986)
  - 73% in Shuttle (Jennings 1998)
- Decreased prevalence and severity in repeat flyers (Davis et al, 1988)

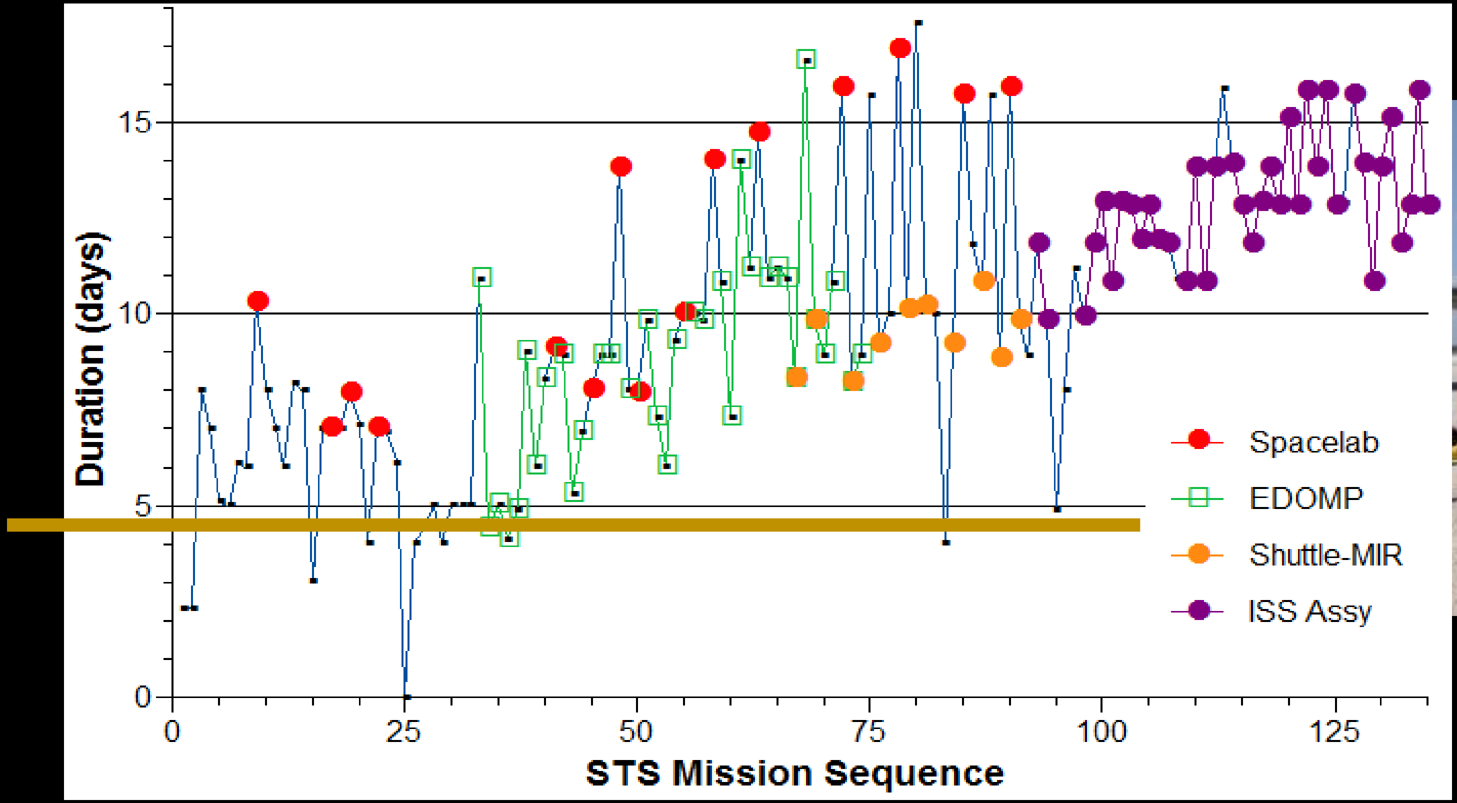


Shuttle
6 crew, 71.5 m^3

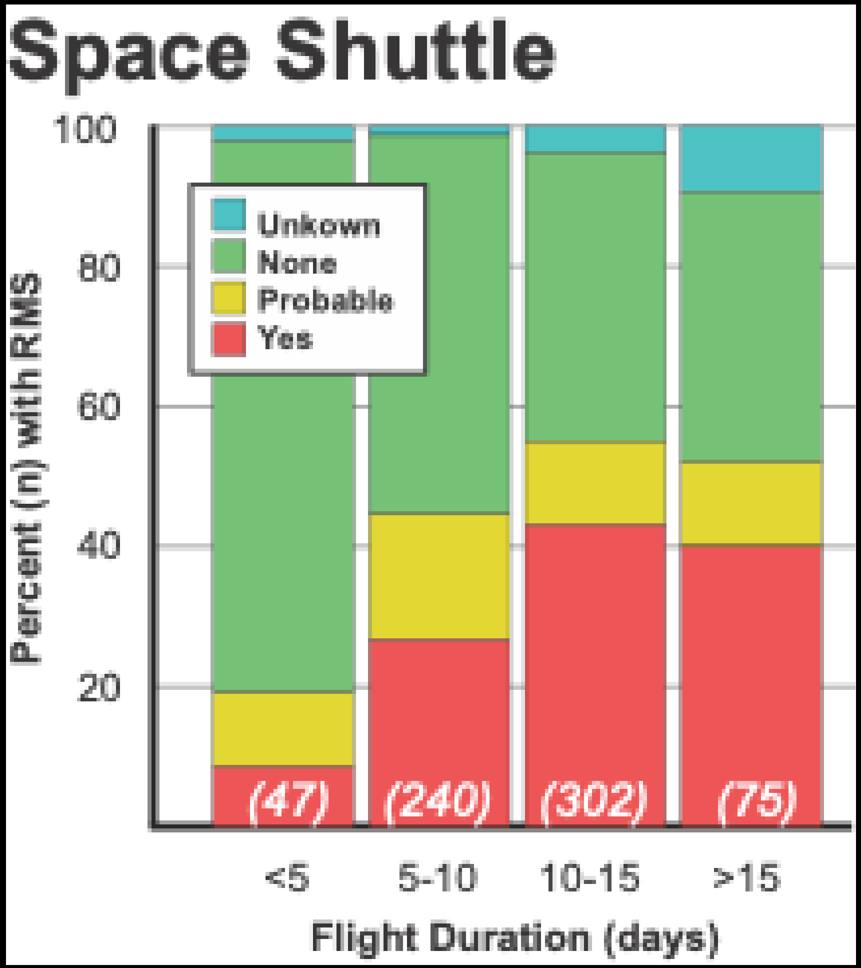
STS reentry motion sickness

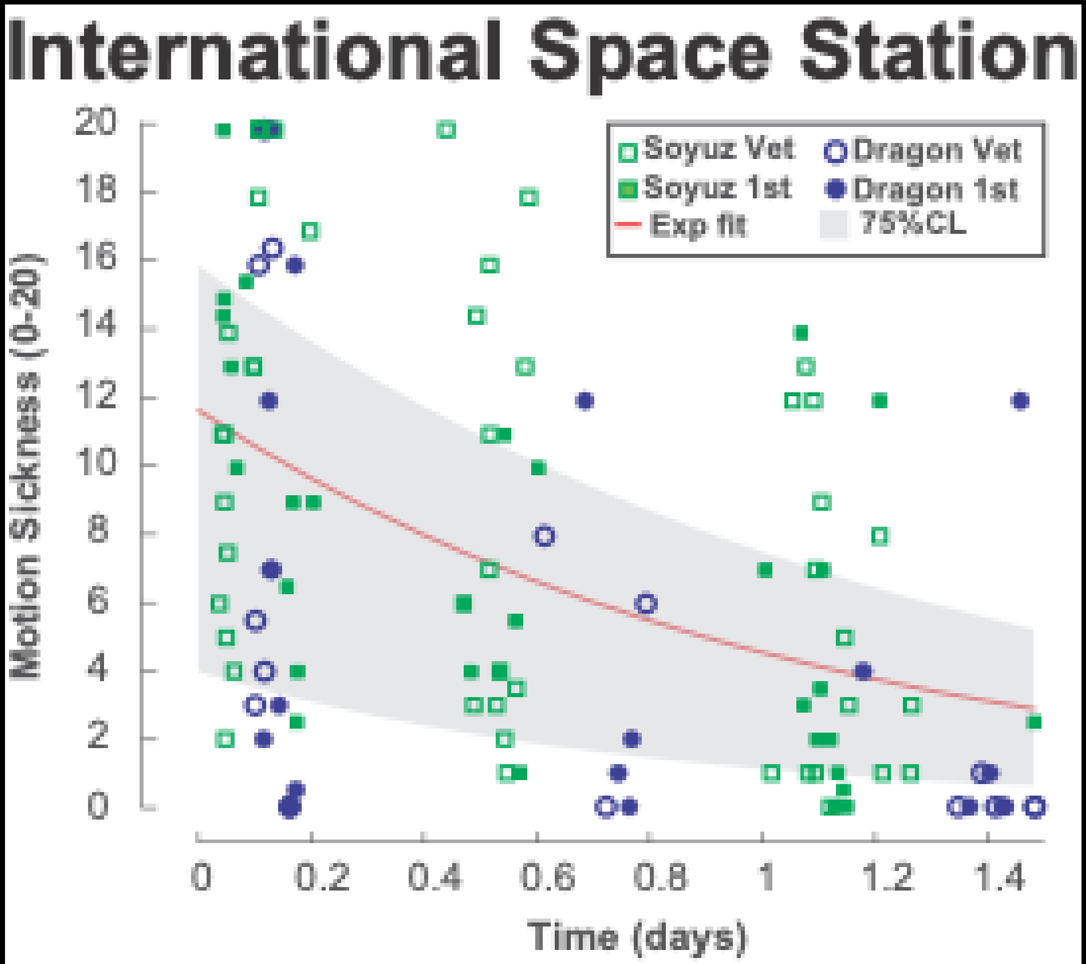
- Prevalence of re-entry nausea was ~15% after Shuttle although majority of crewmembers experiencing movement coordination issues, difficulty walking and persisting sensation after-effects (Bacal et al. 2003)
- Since post-flight impairment was greater with longer flights only CDRs with prior landing experience were considered for flights of extended duration

Apollo transit durations prior to lunar descent



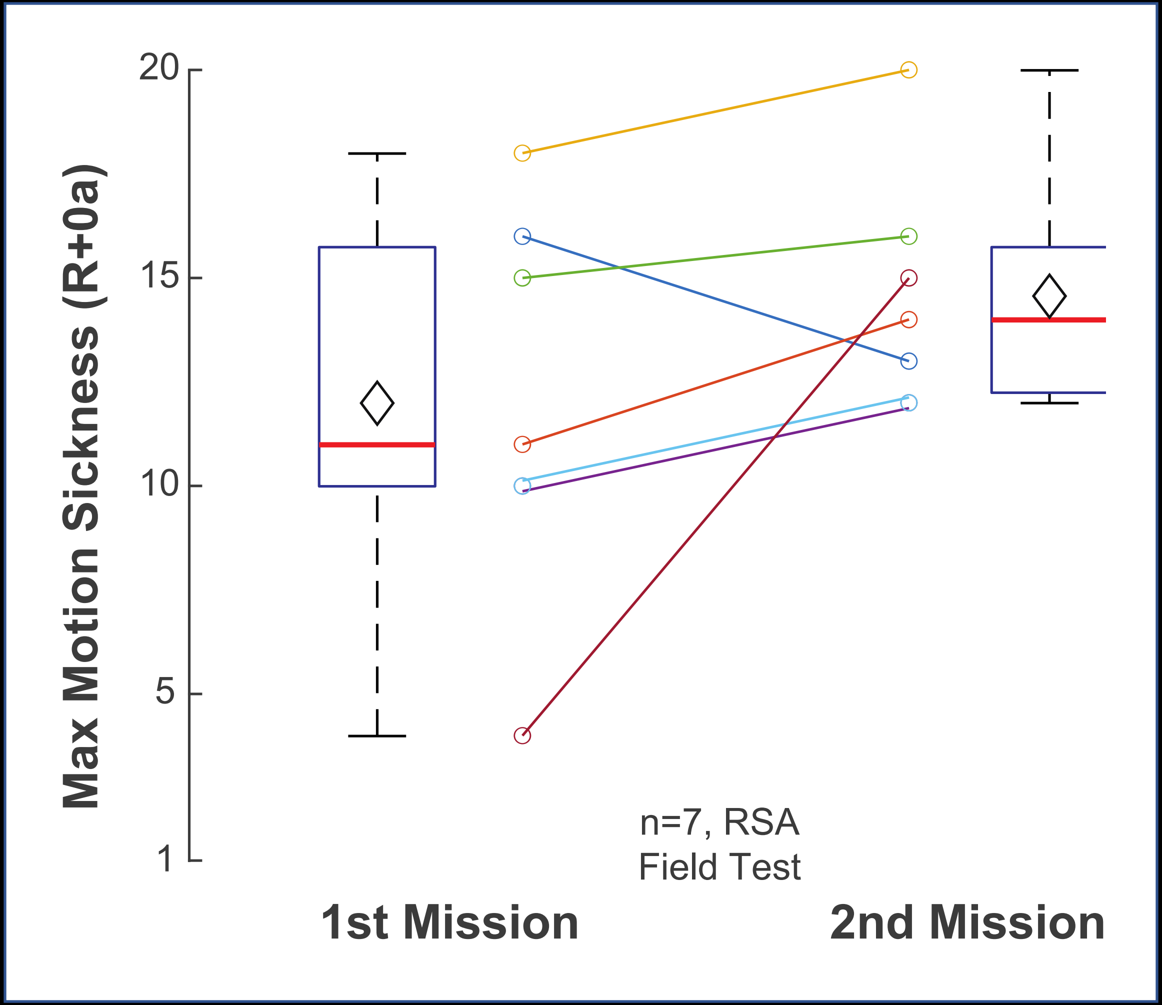
Terrestrial readaptation motion sickness





(1) Shuttle missions 1-135, n=644, data from Lifetime Surveillance of Astronaut Health (LSAH), 2023.
(2) ISS data from expeditions 36-69, n=48

Reentry motion sickness with repeat fliers



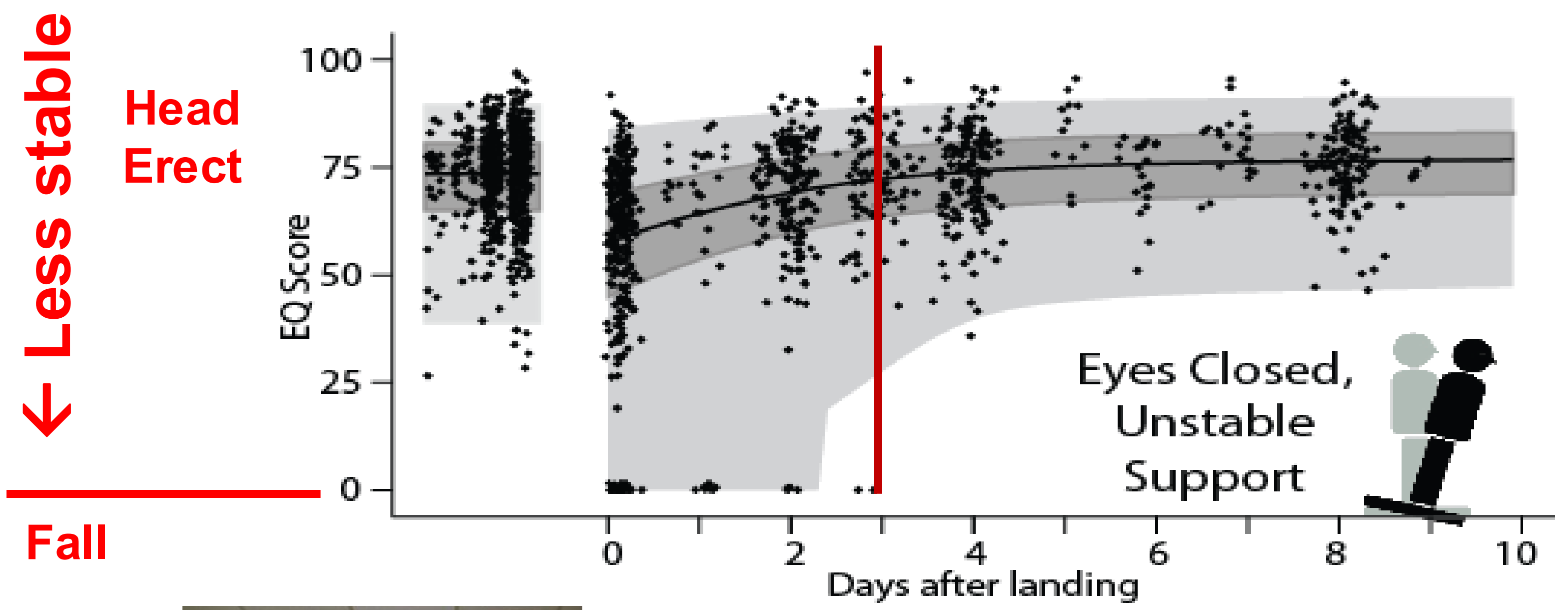
STS post-flight neurological exams

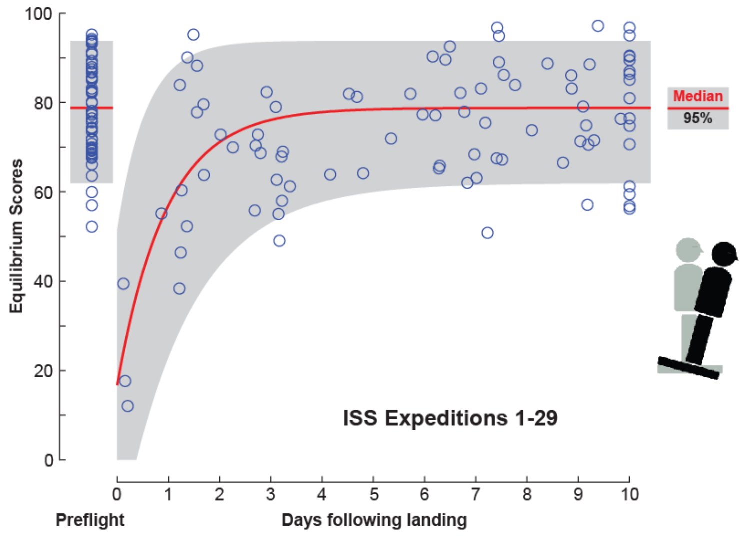
Clark JB. J Vestib Res (2002) 11:321-322

>5% | 0%

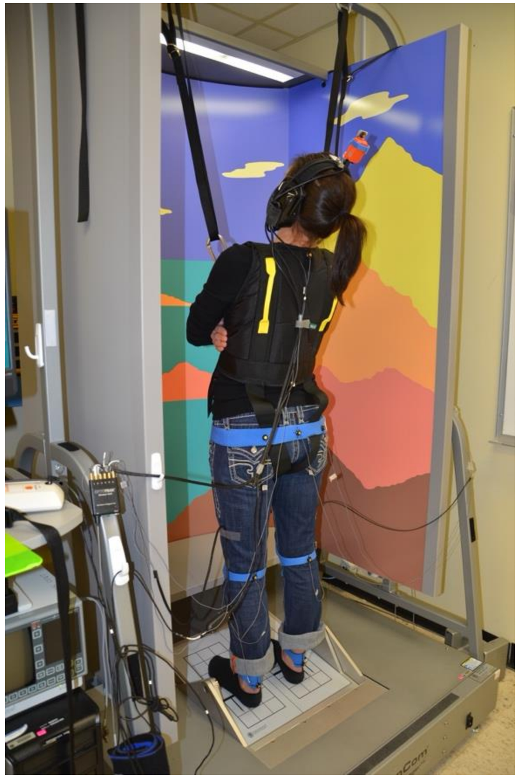
		R+0				R+3			
		None/ Normal	Mild	Moderate	Severe	None/ Normal	Mild	Moderate	Severe
1	**Headache**	94%	3%	2%	1%	97%	3%	0%	0%
2	**Dizziness/Faintness**	83%	14%	3%	0%	98%	2%	0%	0%
3	**Vertigo/Spinning**	88%	9%	2%	1%	99%	1%	0%	0%
4	**Gaze/Eye Movements** (nystagmus)	45%	51%	4%	0%	93%	7%	0%	0%
5	**Finger to Nose** (close eyes touch nose, open eyes touch finger)	81%	19%	0%	1%	99%	1%	0%	0%
6	**Drift** (close eyes, extend arms, palms up)	90%	9%	0%	1%	99%	1%	0%	0%
* 7	**Rising from Chair** (w/o using arms)	86%	11%	1%	2%	99%	1%	0%	0%
* 8	**Standing Romberg** (feet together, extend arms, close eyes; 30 sec)	78%	21%	0%	1%	97%	3%	0%	0%
9	**Hopping** (close eyes, lift leg, hop 3 times, alternate)	60%	26%	9%	3%	99%	1%	0%	0%
* 10	**Tandem Walk** (heel-to-toe; 5 m)	43%	37%	18%	2%	98%	1%	0%	0%
* 11	**Dynamic Equilibrium** (close eyes, walk 9m, turn 180°, return)	53%	41%	3%	4%	93%	7%	0%	0%

Postflight dynamic posturography



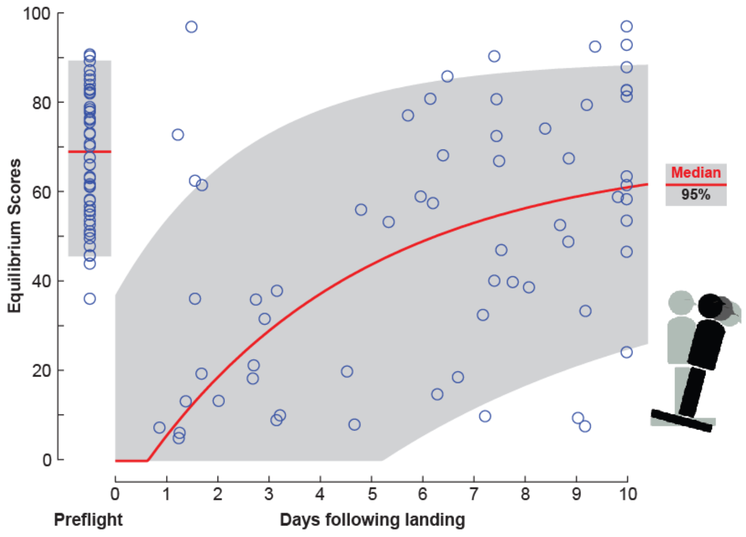


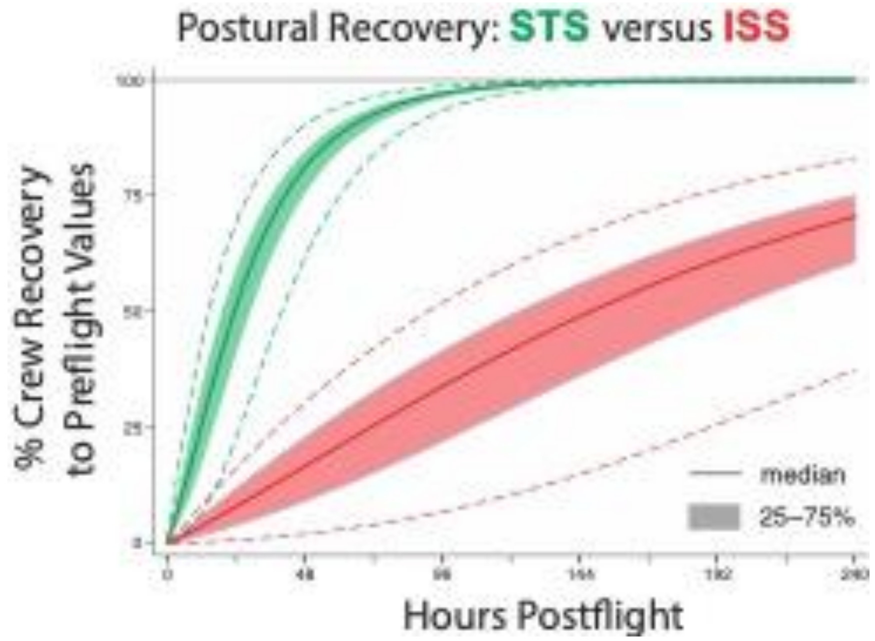
Postflight dynamic posturography



Head Moving

Pitch 0.33 Hz ±20º

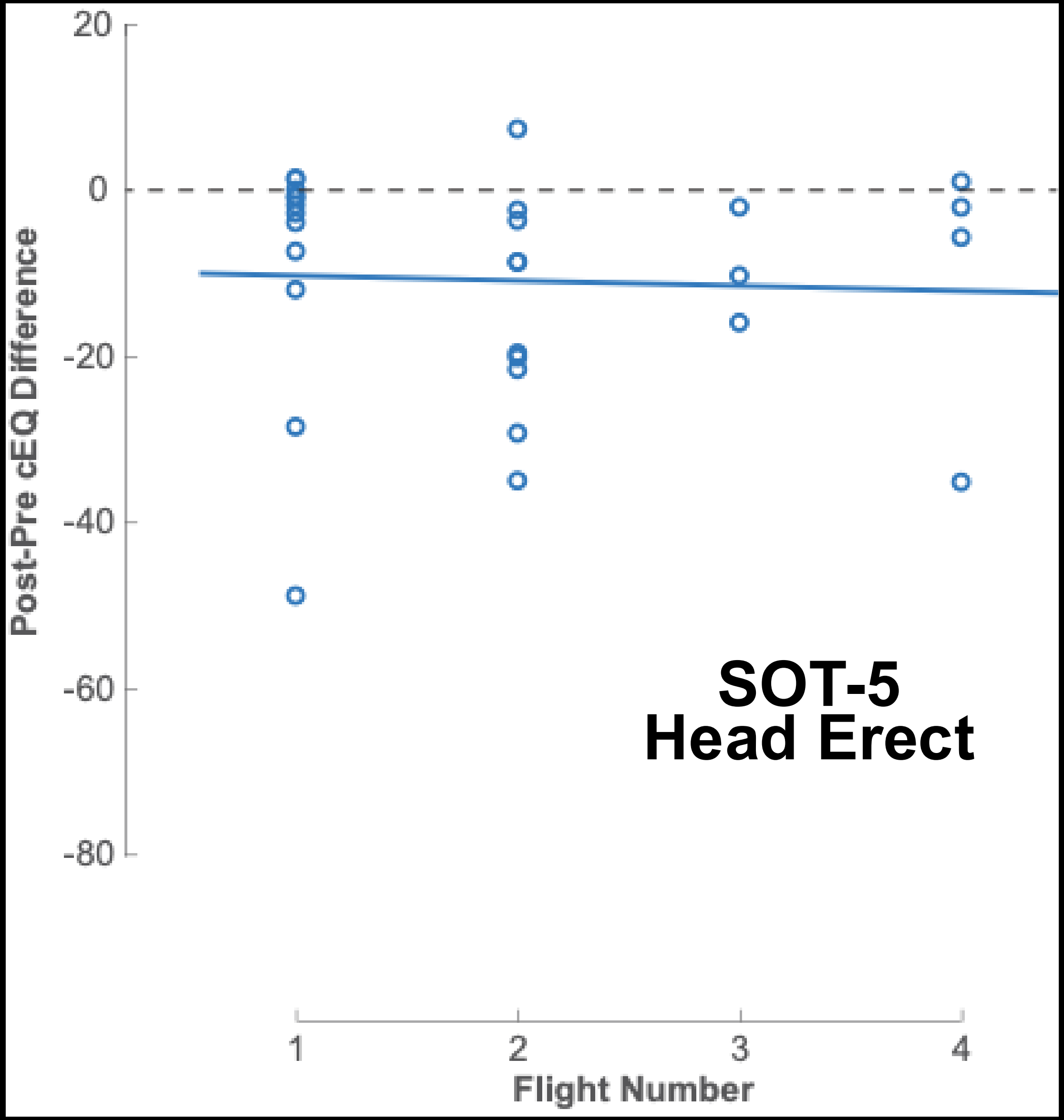


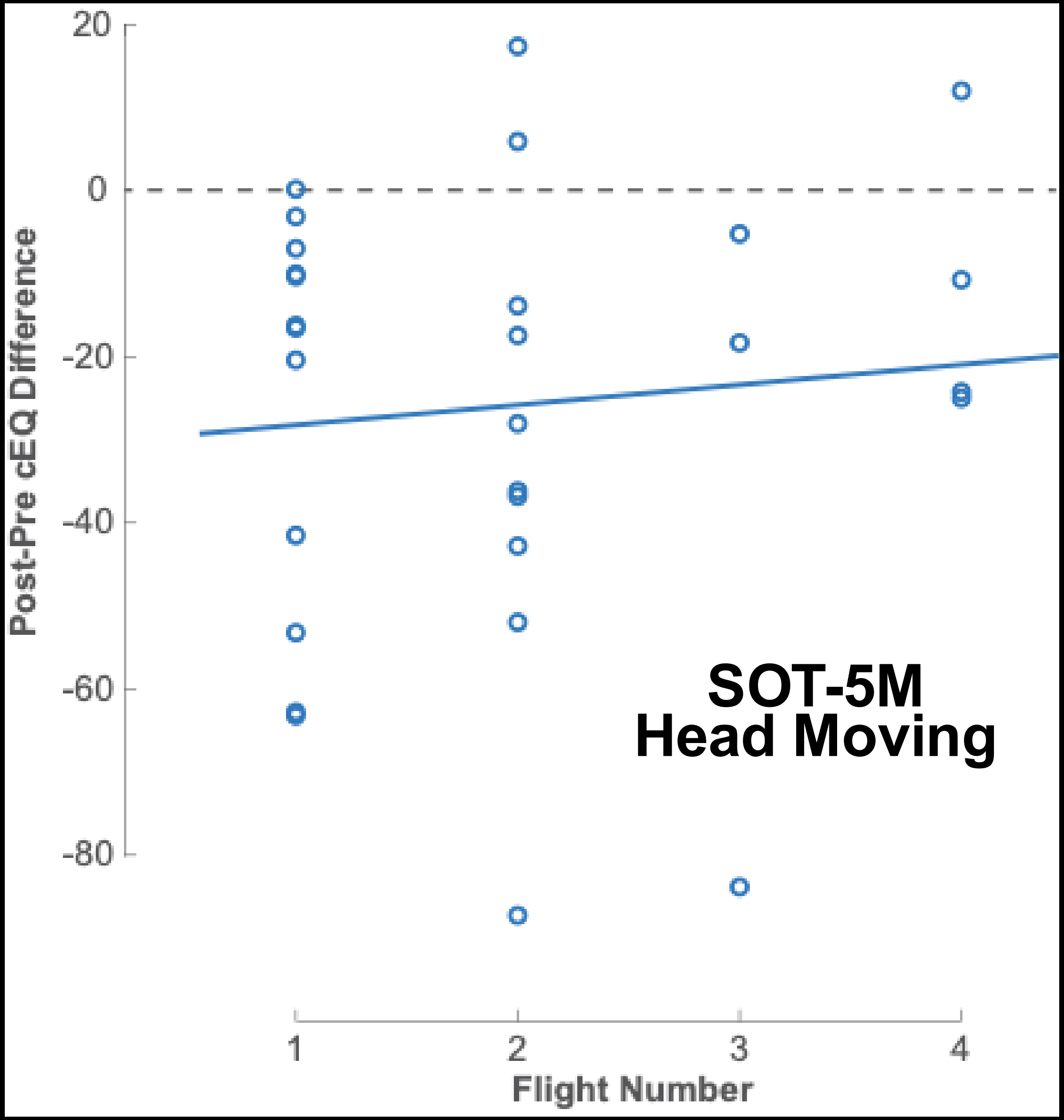


Head Moving

Wood et al., Aviat Space Environ Med (2015)

Effect of prior flight experience





ISS Study Demographics

- Long-duration missions lasting 185.5 ± 45.5 days, mean ± std
- 30 subjects including 9 F and 12 first-time fliers
- Participated in pre/postflight field test battery and posturography

Recovery From Fall (RFF)

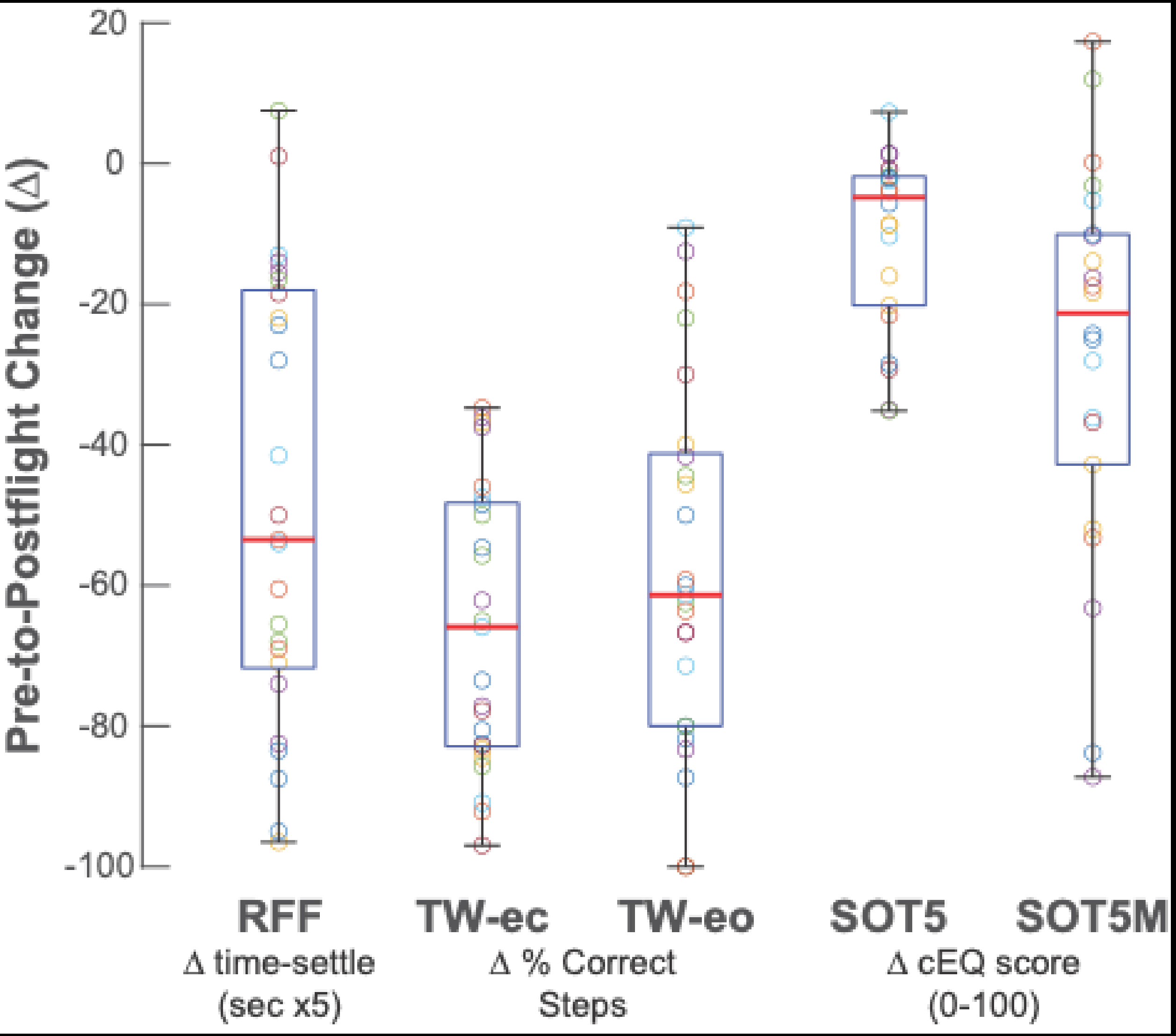
Tandem Walk (TW, eyes open/closed)

Sensory Organization Tests (SOTs)

CDP versus Field Tests at R+1 day

Recovery From Fall (RFF)

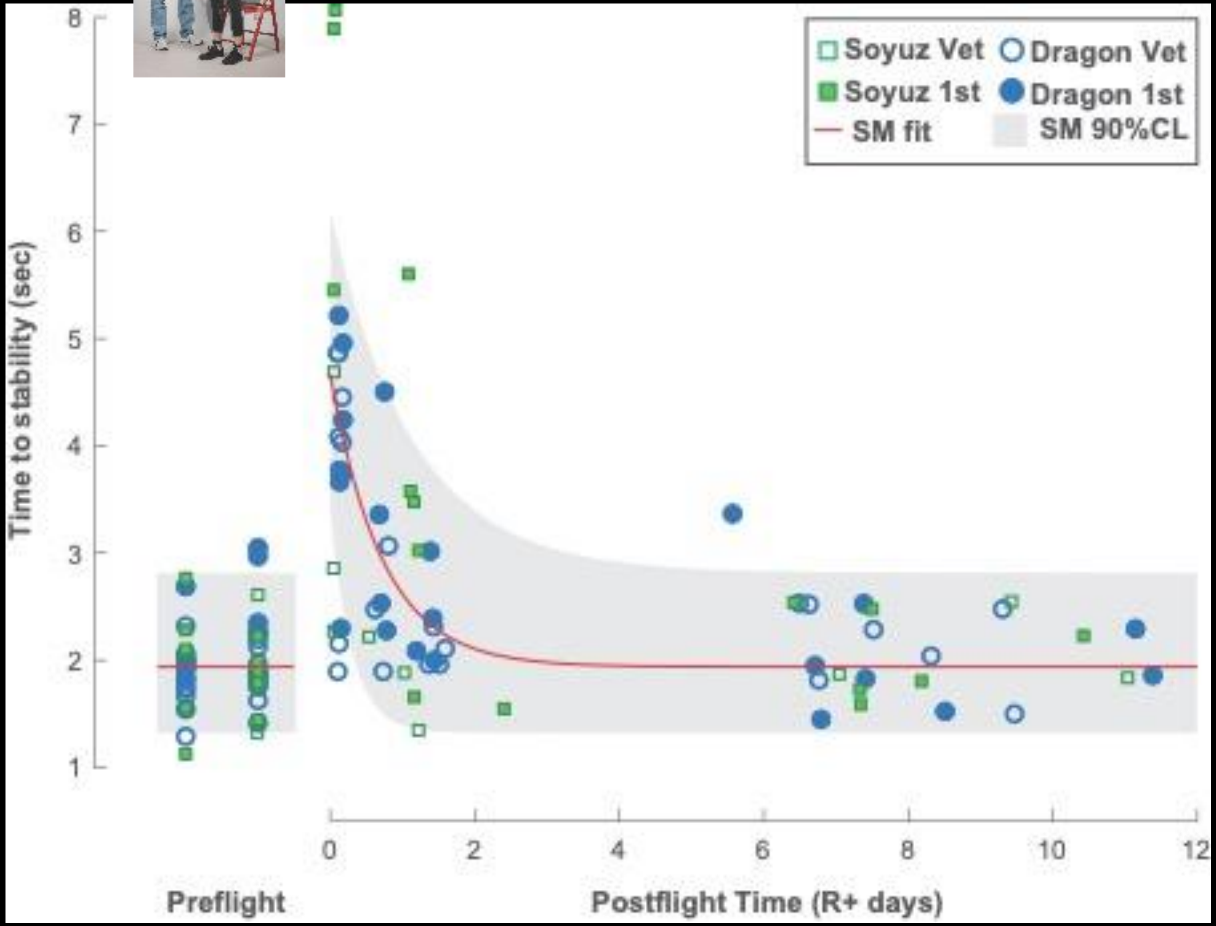
Tandem Walk (TW, eyes open/closed)



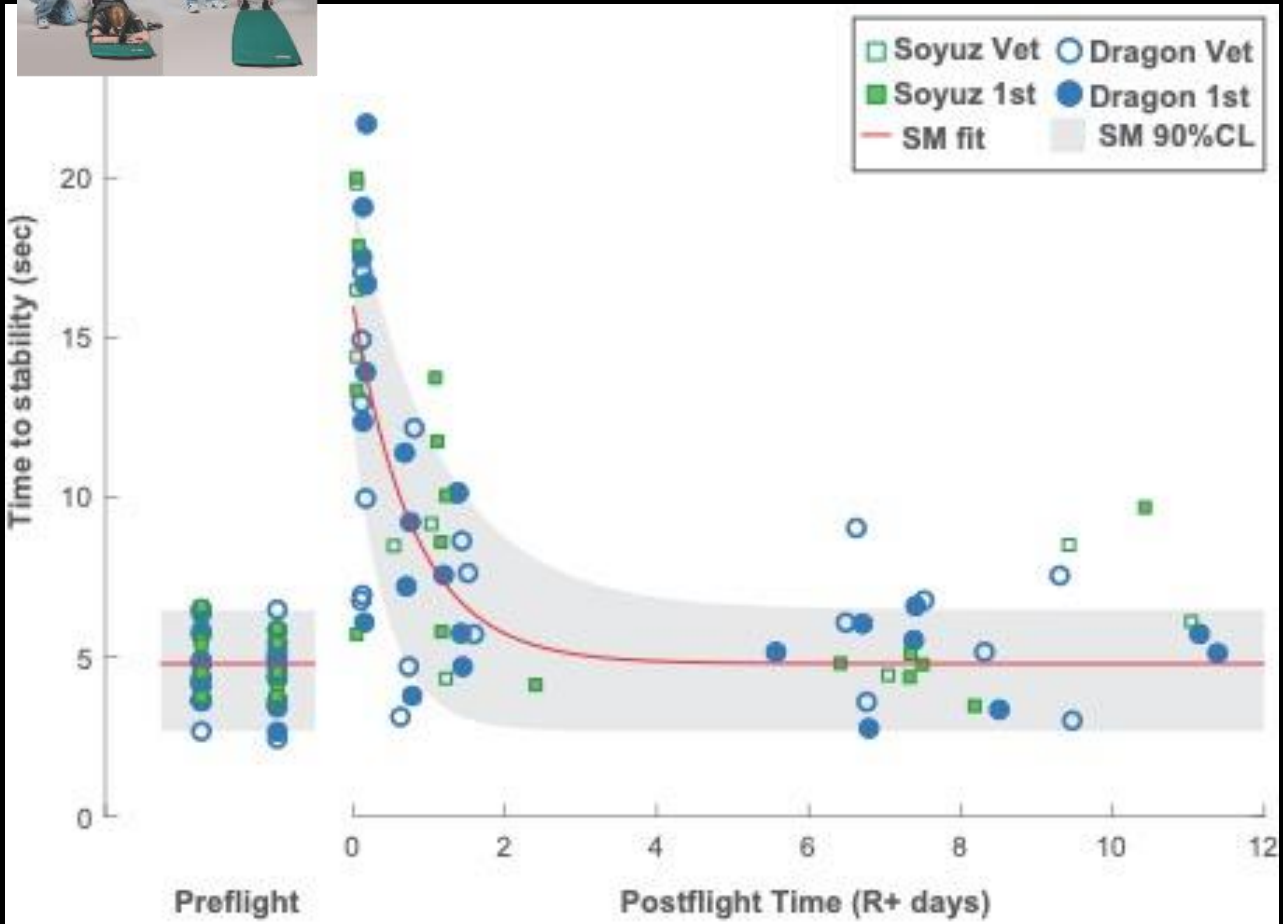
Computerized Dynamic Posturography (CDP)

Balance tasks by vehicle / experience

Sit-to-stand



Recovery from fall



N=24

Tandem walk eyes closed: short versus long

STS Short

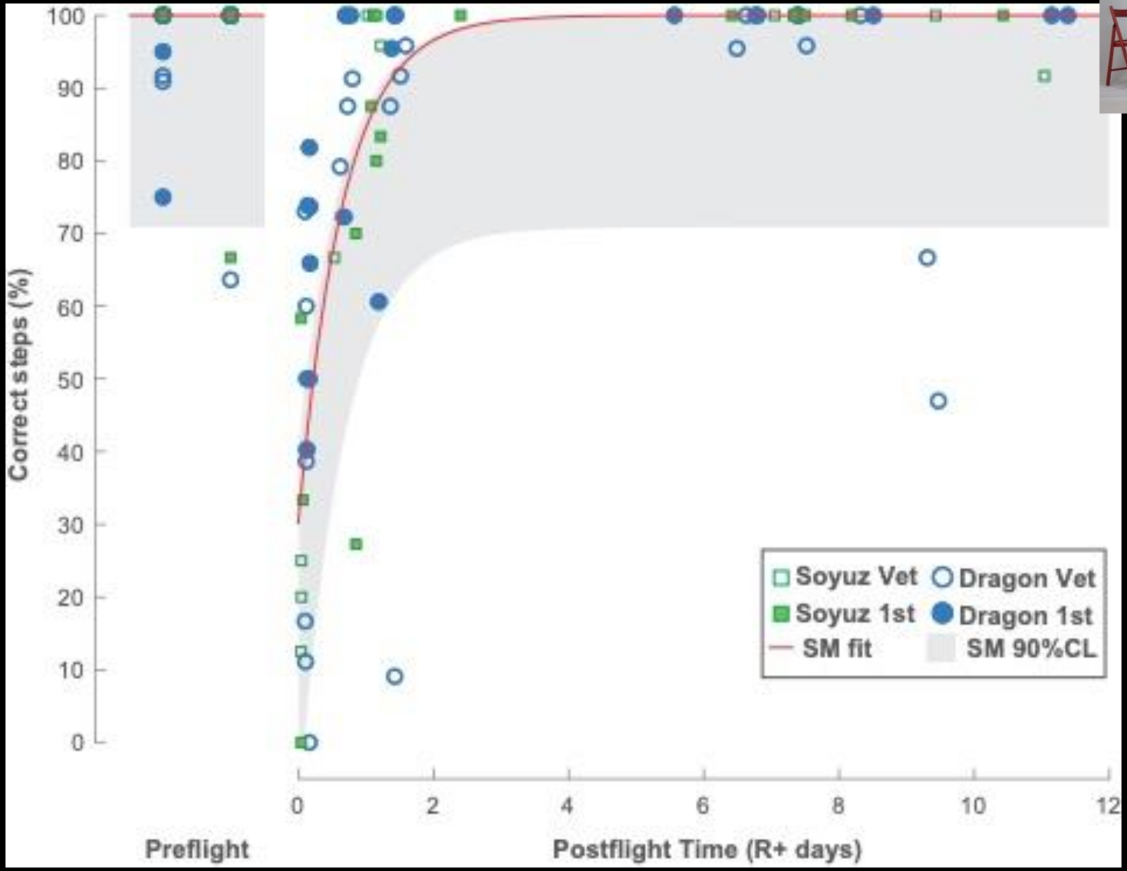
Preflight

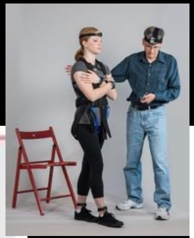
R+0

ISS - Long

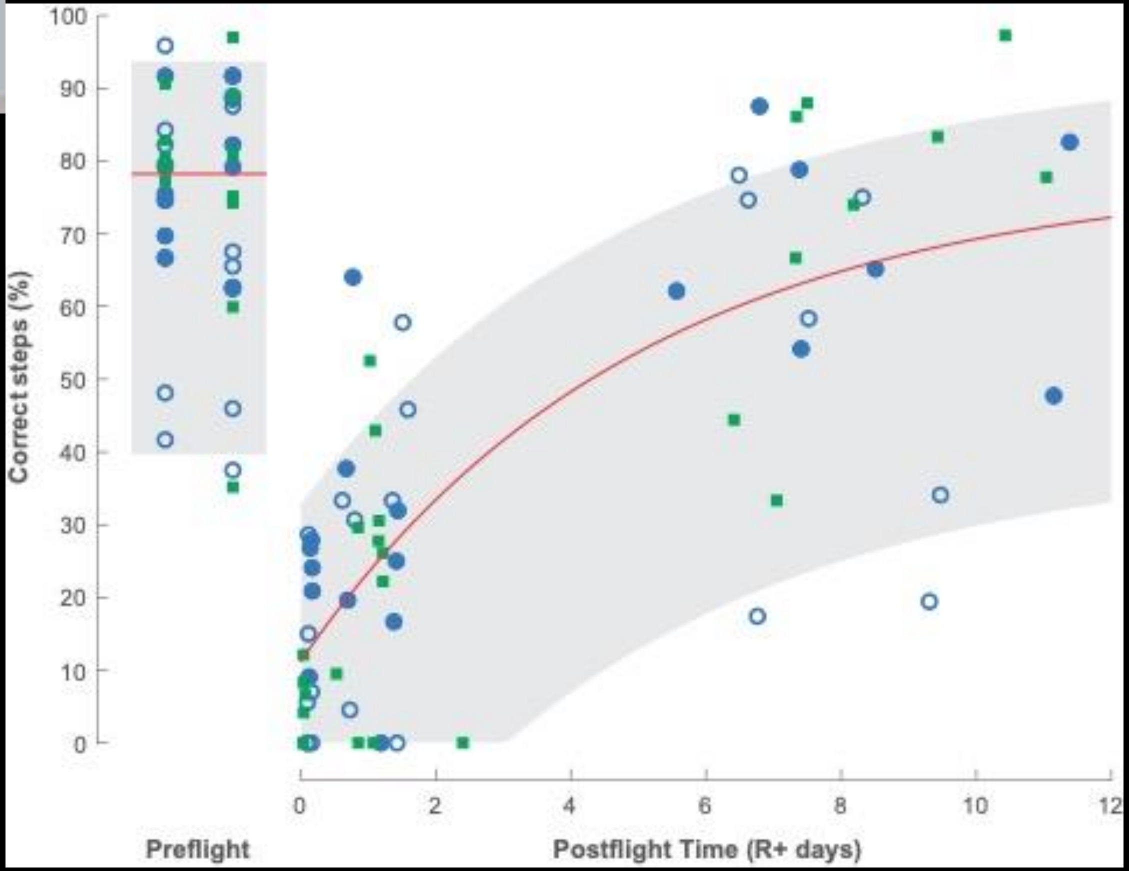
Tandem walking by vehicle / experience

Eyes Open





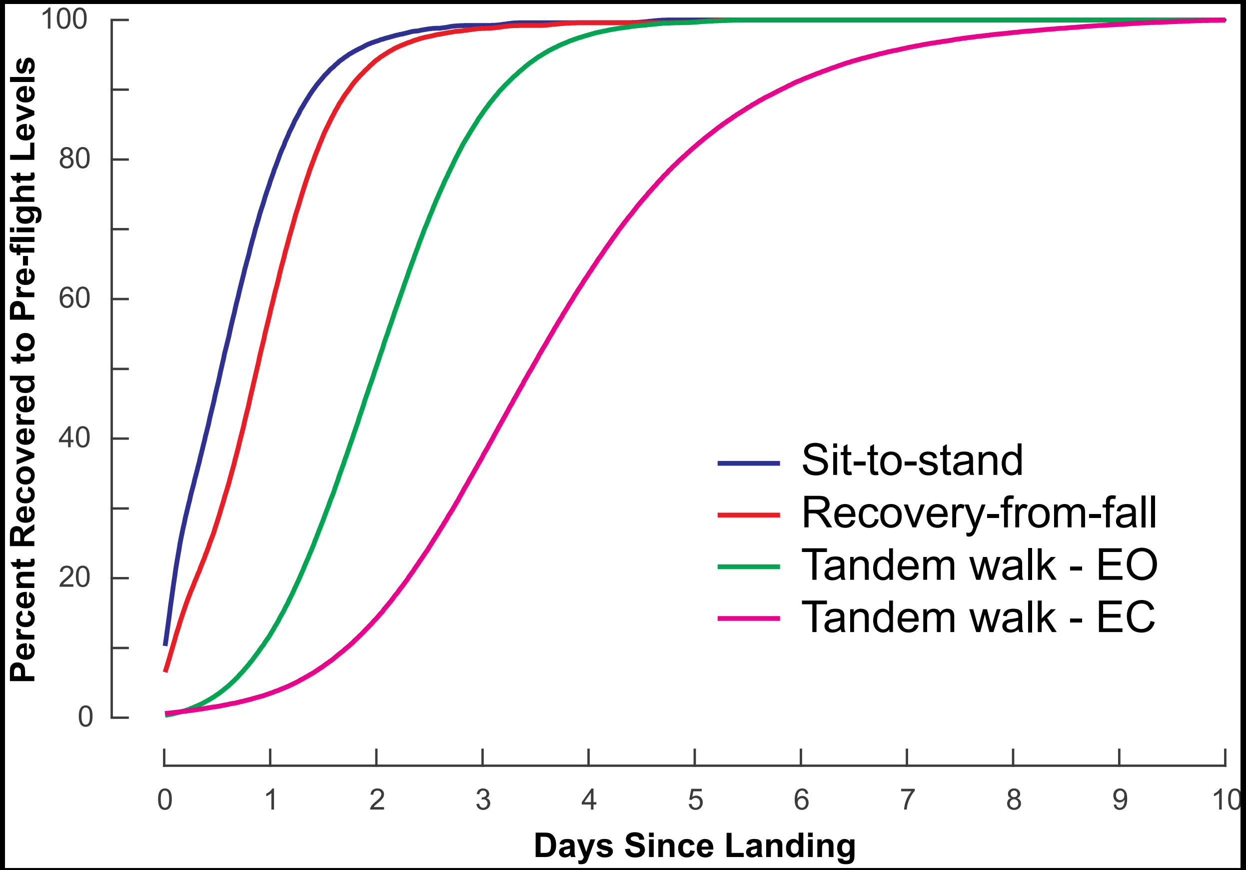
Eyes Closed



N=24

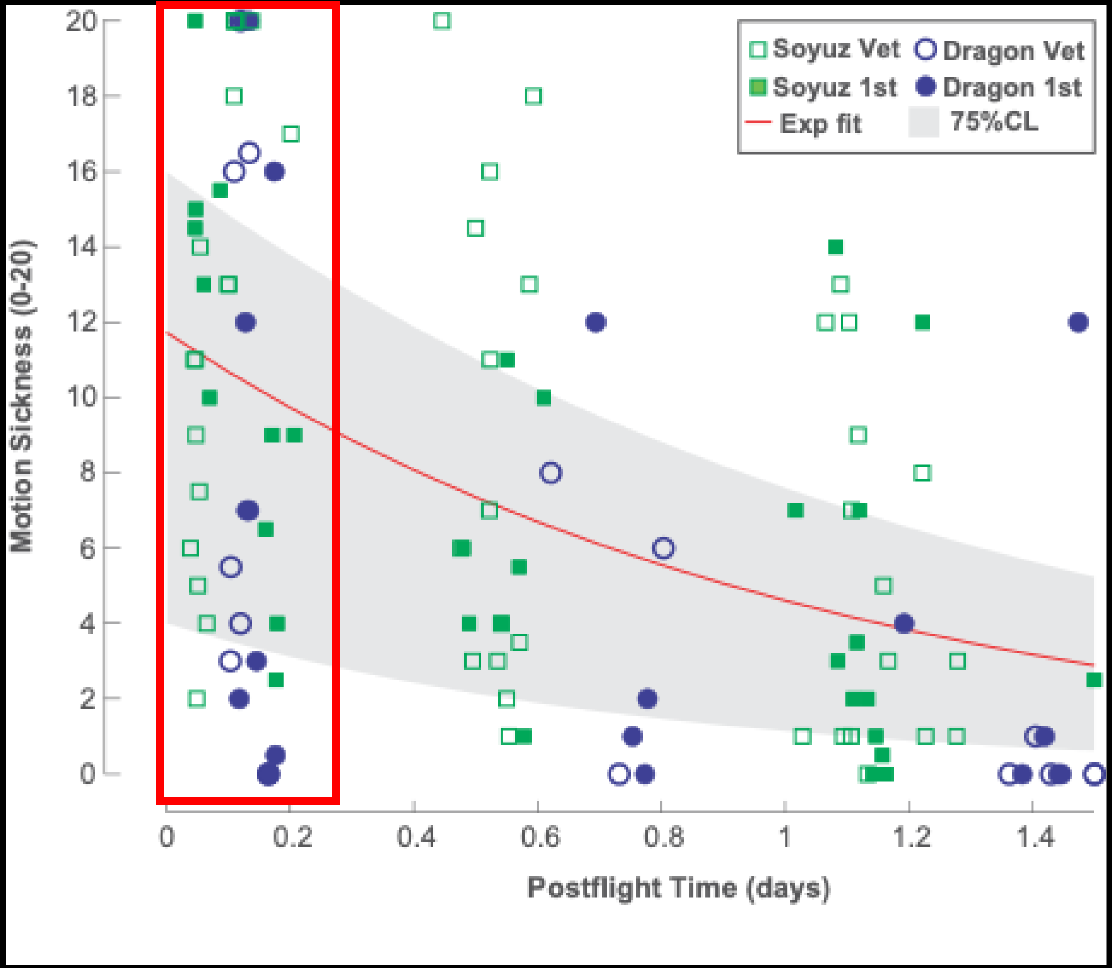
Comparison across tasks

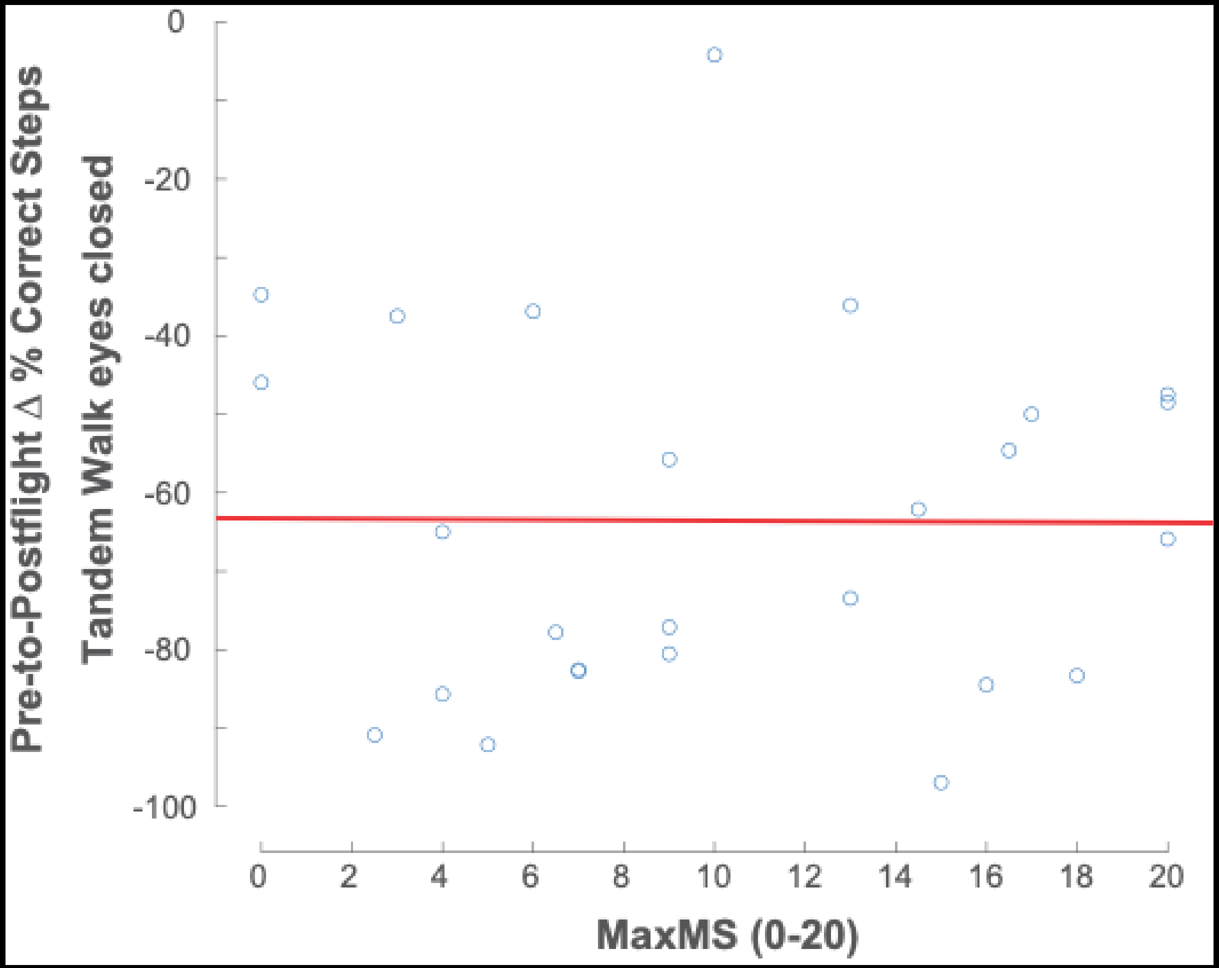
- The recovery timeline varied with task complexity, generally taking longer when either the basis of support was limited (e.g., tandem walk) and/or visual cues were deprived (eyes closed)



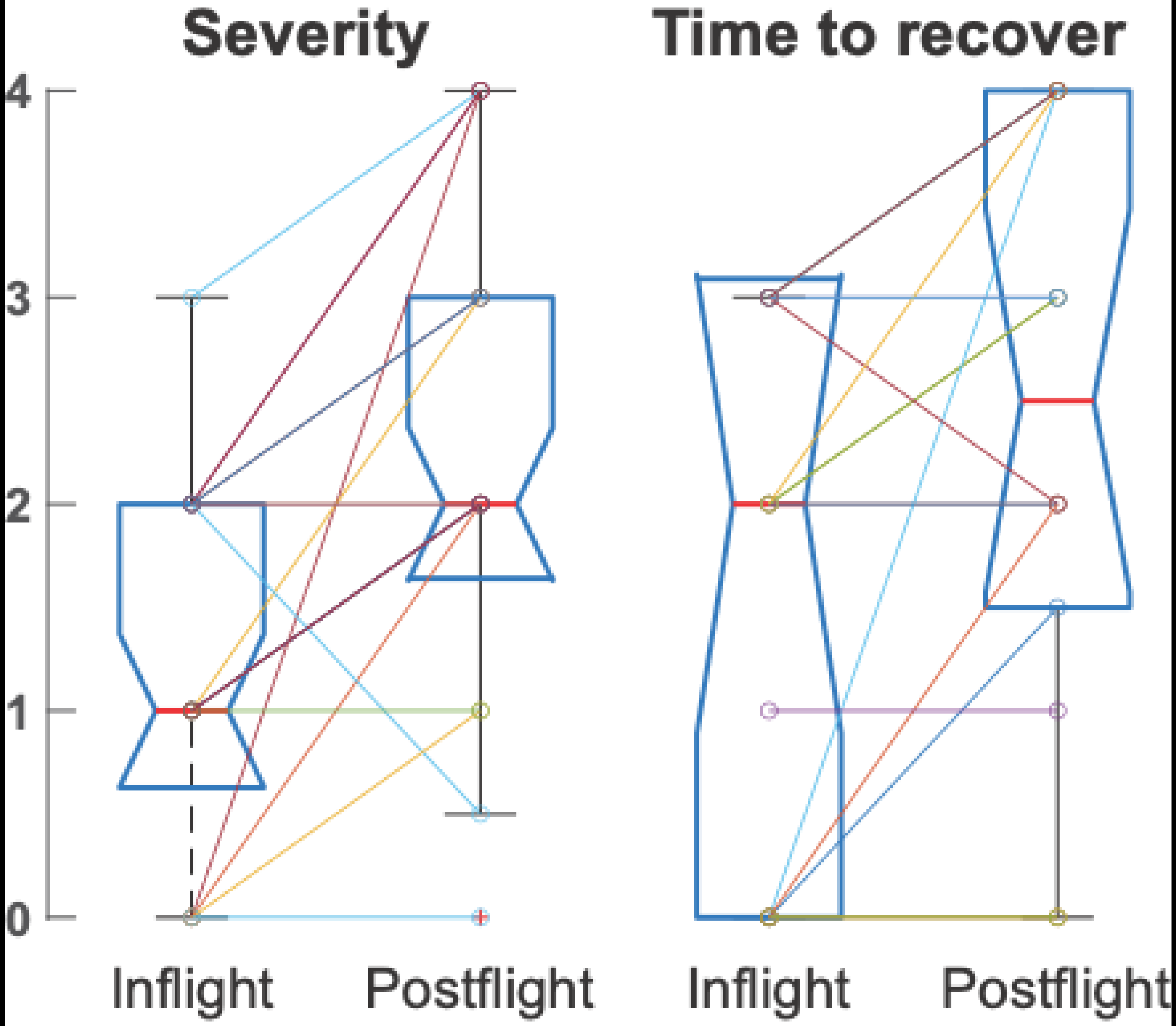
Recovery curves from Field Test

Terrestrial Readaptation Motion Sickness





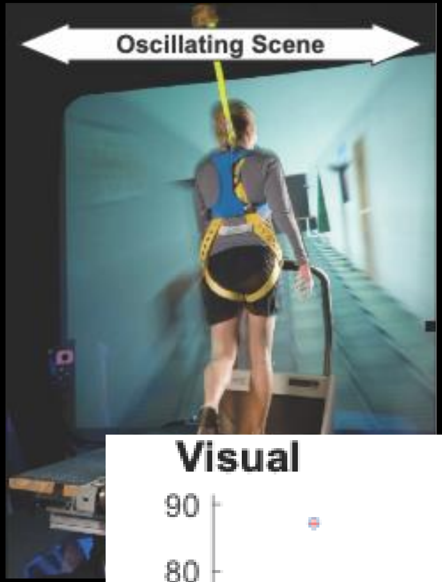
Inflight versus reentry: Functional impacts

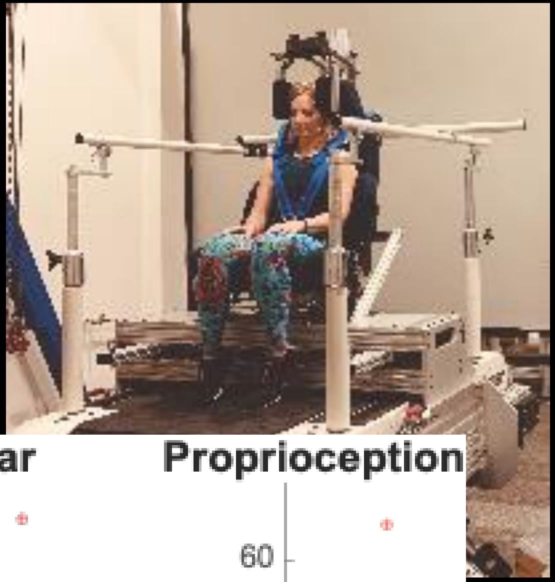


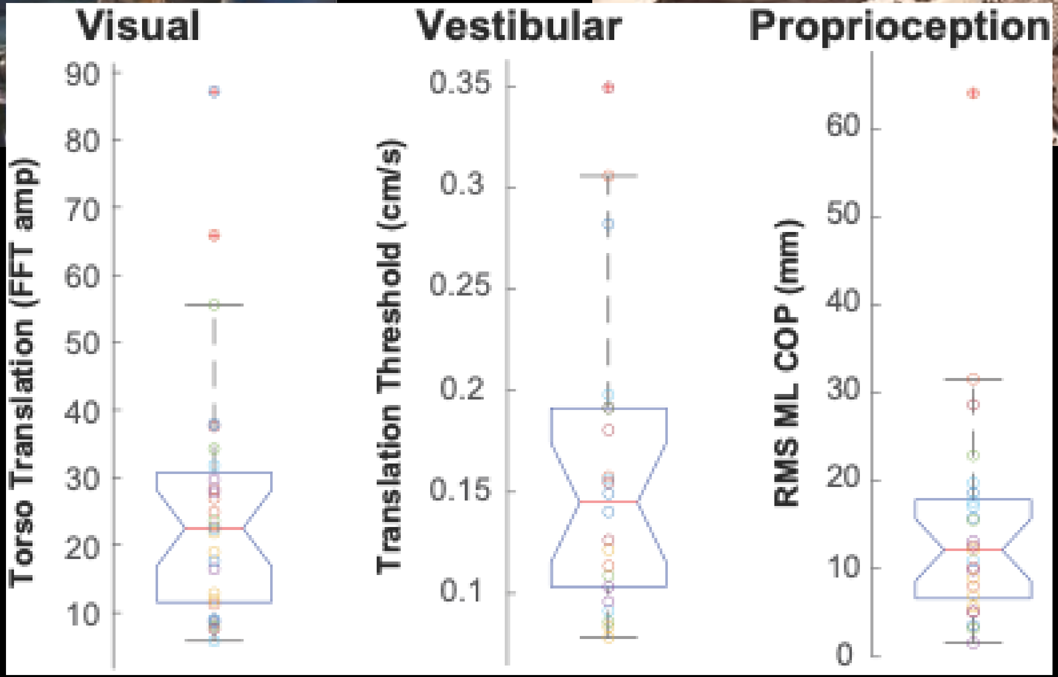
Severity
4 Severe, tasks not attempted
3 Moderate, extended time req'd
2 Mild, transient, worse with motion
1 Functioning nominally, increased effort
0 No impact or restriction of movement

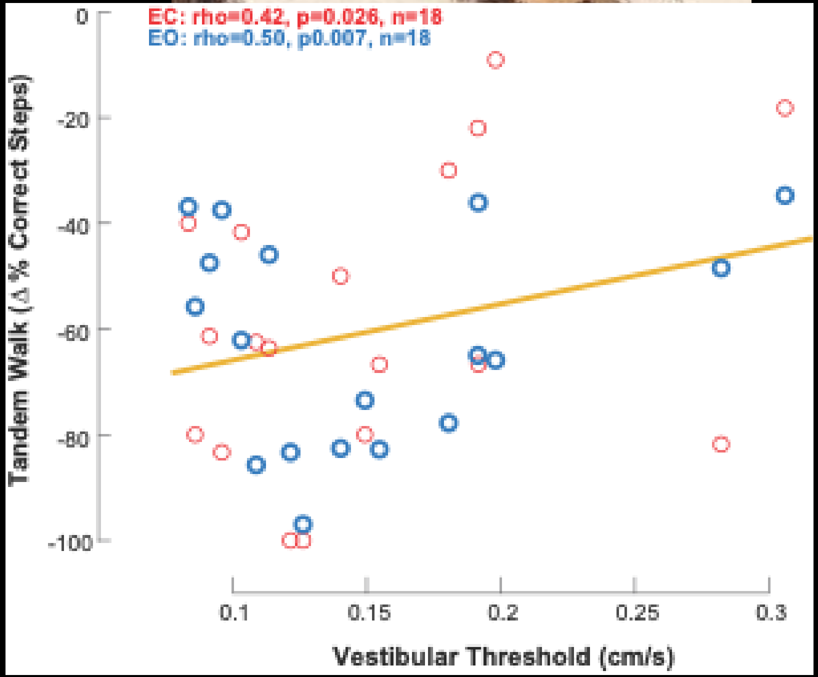
Time to Recover
4 More than 3 days
3 Between 1 -3 days
2 Between 6 hrs and 1 day
1 Less than 6 hrs
0 No impact or restriction of movement

Sensory Dependency



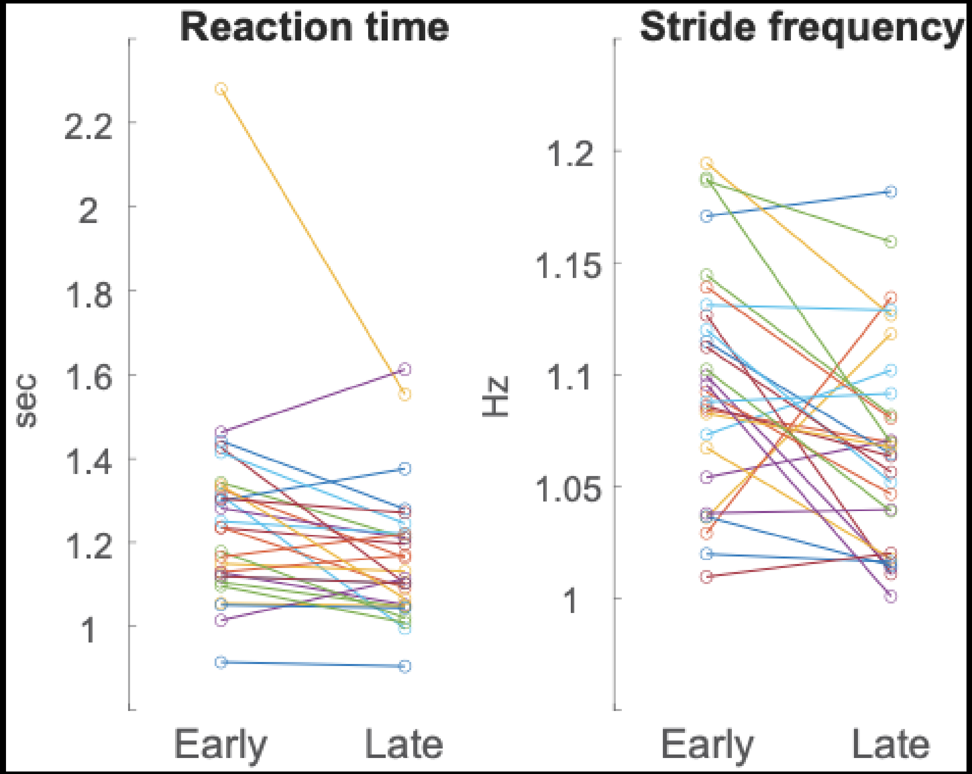




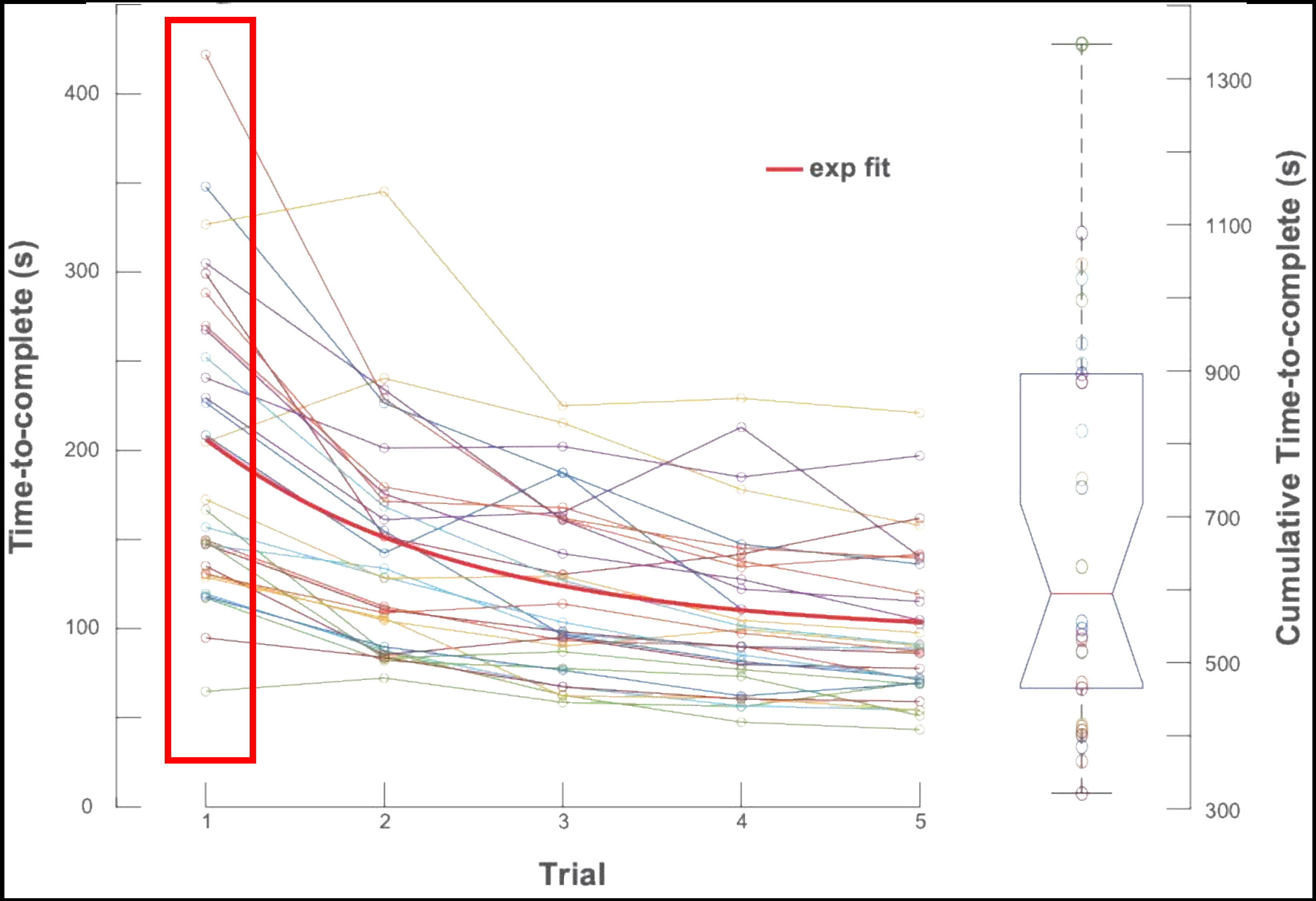


Biomarker of adaptability

- Ground assessment of adaptability was assessed with changes in stride frequency and reaction time to an auditory cue while walking with a virtual linear hallway on an oscillating treadmill



Adaptive Functional Mobility Test

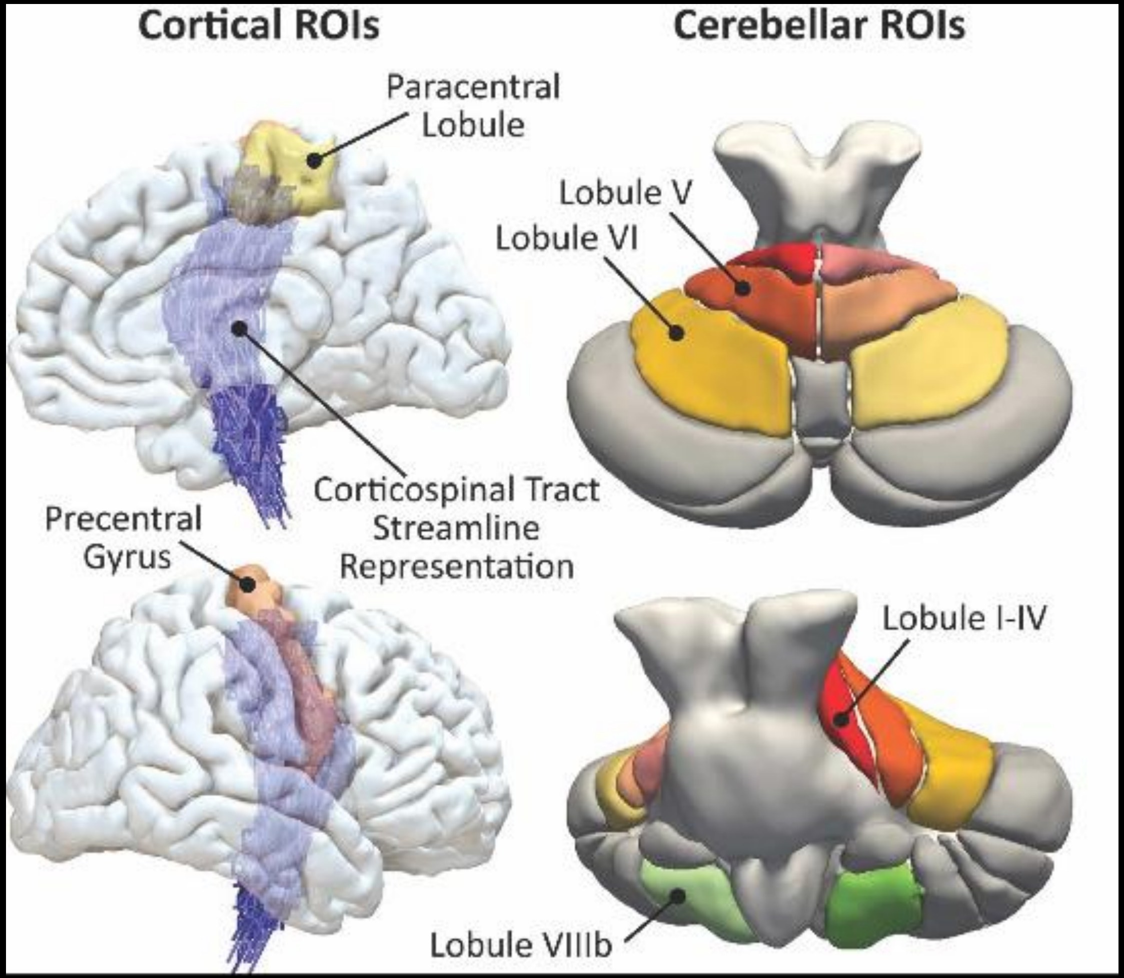


Ground assessment of adaptability was performed during multiple trials of navigating an obstacle course while wearing reversing prisms

Neuroimaging

- Preflight medical neuroimaging were examined to derive individual differences in regional brain volumes (using Structural MRI) and white matter microstructure (using Diffusion Tensor Imaging) as potential predictors of adaptive capacity
- Preselected regional measures of gray matter volume (e.g., motor cortex, paracentral lobule, cerebellum), myelin density (motor cortex, paracentral lobule, corticospinal tract), and white matter microstructure (corticospinal tract) were derived as a-priori predictors. Additional whole-brain analyses of cortical thickness, cerebellar gray matter, and cortical myelin were also tested for associations with pre-to-post-flight motor performance.
- The pre-selected regional measures were not significantly associated with motor behavior.

Neuroimaging



Koppelmans et al., Brain Struct Funct, 2022.

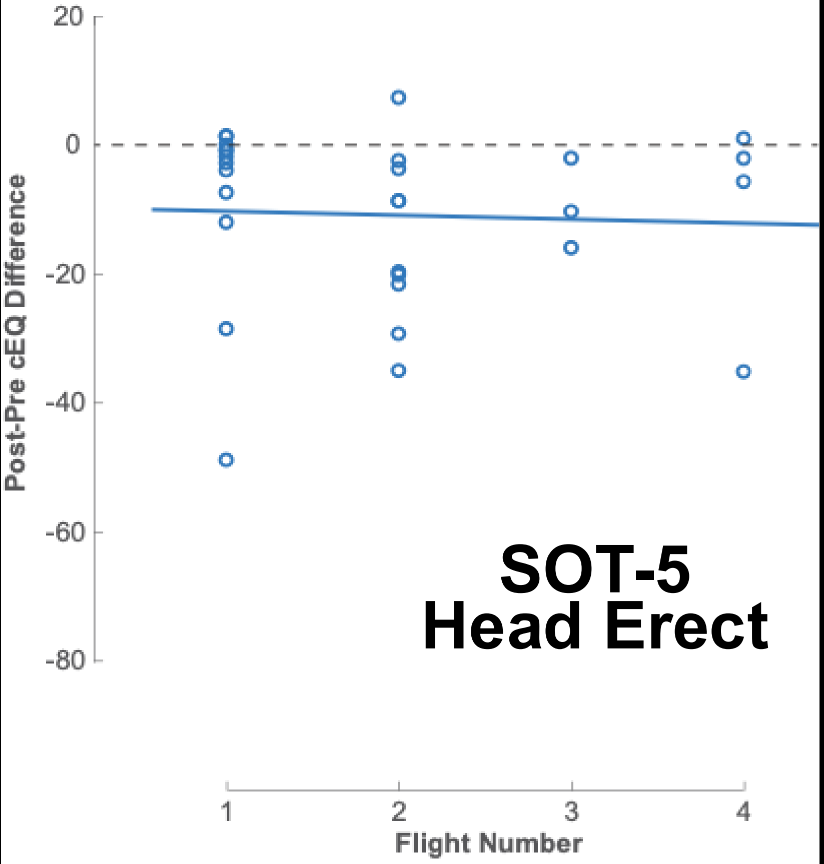
- Whole-brain analyses showed that paracentral and precentral gyri thickness significantly predicted recovery from fall post-spaceflight
- Thickness of vestibular and sensorimotor regions, including the posterior insula and the superior temporal gyrus, predicted pre-to-post-flight decrements

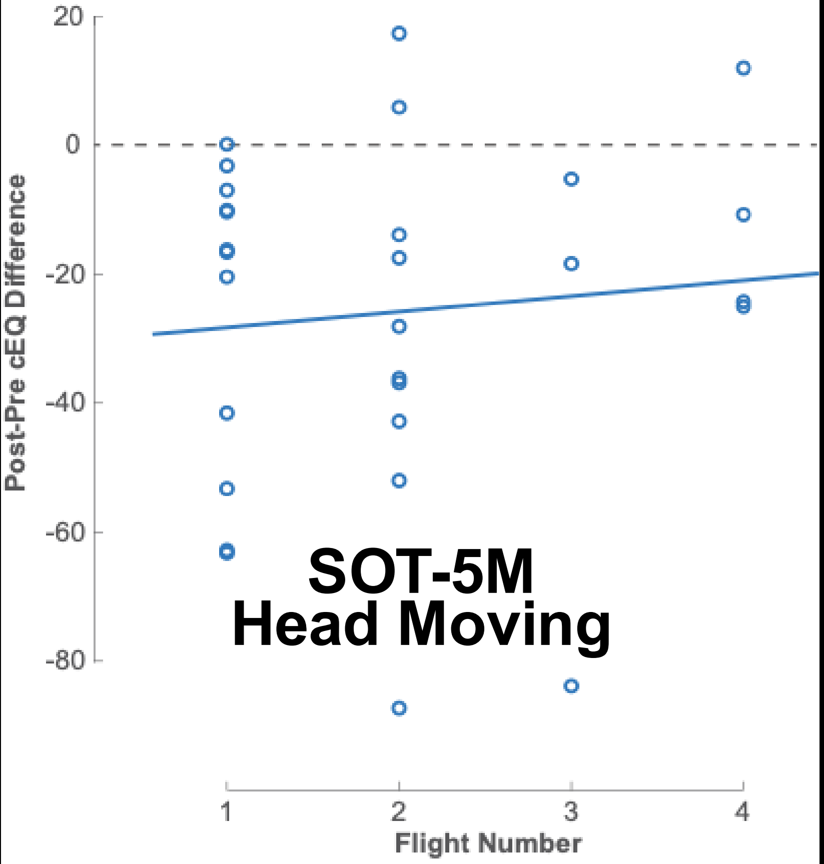
Genetic biomarkers

DRD	COMT	BDNF	Dral	Δ TW-EC
GG	VM	VM	TGA/TAA	-97.0
TT	VM	VM	TGA/TGA	-90.9
GG	MM	VV	TAA/TAA	-87.9
GG	MM	VM	TGA/TAA	-77.8
GG	MM	VV	TGA/TGA	-76.8
GG	VM	VV	TGA/TGA	-66.7
GG	MM	VM	TGA/TGA	-65.9
GT	VV	VV	TGA/TAA	-61.1
GT	VV	VM	TGA/TAA	-50.4
GG	MM	VV	TGA/TAA	-50.0
GG	VV	VM	TGA/TGA	-48.5
GT	VV	VV	TGA/TGA	-46.9
GG	MM	MM	TGA/TGA	-46.0
GG	VM	VV	TAA/TAA	-42.7
GG	MM	VV	TGA/TGA	-40.0
TT	VM	VV	TGA/TAA	-36.0
GG	MM	VV	TGA/TGA	-34.8
GG	VV	VM	TGA/TAA	-33.0
GG	MM	VV	TGA/TGA	-31.3
GT	VV	VV	TGA/TAA	-30.7
GG	VV	VM	TGA/TAA	-29.2
GG	VM	VV	TGA/TGA	-28.0
GT	VM	VV	TGA/TAA	-24.0
GG	VM	VM	TGA/TGA	-21.7
GG	VM	VM	TGA/TGA	-21.2
GG	MM	VM	TGA/TGA	-18.9

- Examined Dopamine Receptor D2 (DRD2), Catechol-O-methyltransferase (COMT), Brain-derived neurotrophic factor (BDNF) and the α2-adrenergic receptor
- While these differentiate sensorimotor adaptability in a terrestrial population, no patterns with post-flight measures have emerged

Effect of prior flight experience





Post-flight outcome measures did not vary by prior flight experience, but when available, were consistent across flights within individuals

Conclusions

- The duration of microgravity exposure influences the time course of recovery to preflight performance levels
  - Longer microgravity transits to the moon may require more time for recovery
- There is large intersubject variability, and in contrast with ocular counter roll, motion sickness and postflight postural performance does not appear to be consistently altered with prior flight experience
  - Exploration type assessments will be needed to help crewmembers understand their readiness for different surface mission tasks

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EXPLORE
MOON to MARS