Relationship Between Fatigue And Cognitive Function During Orthostatic Challenge: A Neuroergonomics Approach

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Background

- Acute orthostatic intolerance (OI)
  - Changes in blood flow and pressure due to environmental stressors such as standing[1]
- 64% of astronauts in short duration and 80% astronauts in long duration missions suffer from OI[2,3]
- Neurovestibular alterations[4]
  - Disorientation
  - Impaired coordination
  - Impaired cognition
  - Syncope (loss of consciousness)

1 Mukai et al., 2002; 2 Buckey et al., 1996; 3 Meck et al., 2001; 4 Mark & Heldt , 2005

Background

- Long duration space missions[1]
  - Fatigue and workload
  - Sleep deprivation, long workdays, circadian rhythms
  - High-risk environments
- Physiological reactivity of OC with stress[2]
- Type of cognitive function affected remains unclear
  - Psychomotor tasks: needed for control and maneuvering
  - Attentional demands: High-level cognitive skills

1 NASA, 2011; 2 Durocher et al., 2008

Problem Statement

- Investigating the effects of fatigue on cognitive function during orthostatic challenge (OC)
- Exploring neural correlates of different cognitive stressors during OC

Hypotheses

1. Fatigue will adversely affect neural correlates of performance during OC
2. The type of cognitive stressors will influence this relationship

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Experimental Design

FATIGUE
No Fatigue
Fatigue

x

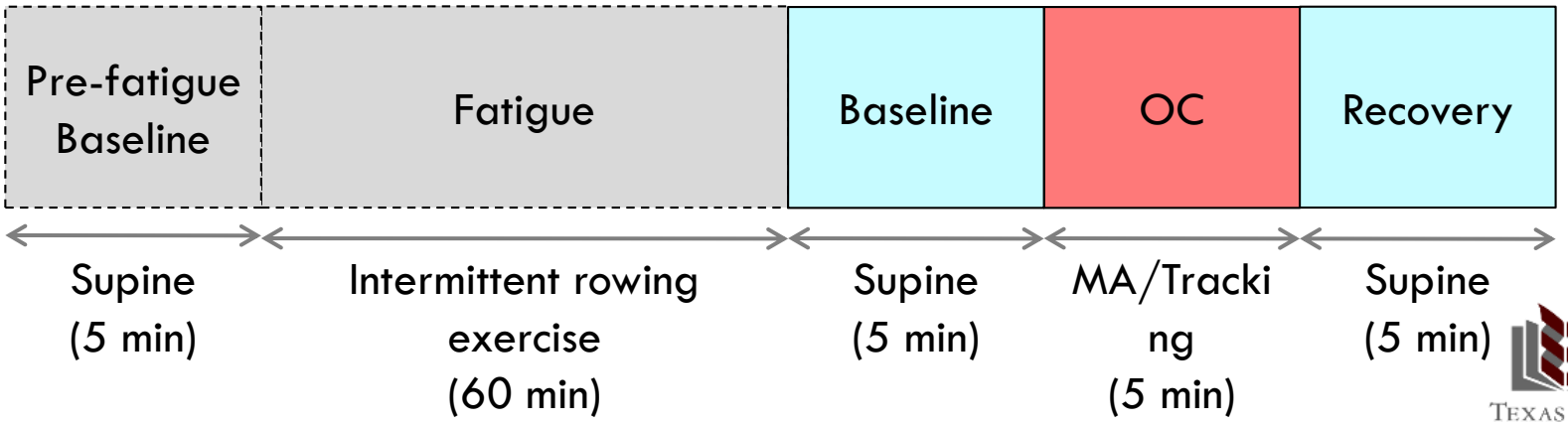
COGNITIVE STRESSOR
Mental Arithmetic
Tracking

- Participants
  - 16 athletes (balanced by gender)

Gender	Age	Height	Weight
Males (n=8)	20.71 (1.4) years	183.15 (9.1) cm	84.93 (11.3) kg
Females (n=8)	19.88 (0.6) years	169.31 (4.6) cm	63.88 (5.4) kg

Protocol

- Orthostatic challenge: Lower Body Negative Pressure (LBNP)[1] at -40mmHg pressure for 5 minutes
- One control (only OC) and 4 experimental (OC+ cognitive stressor) sessions



1 Convertino 2001

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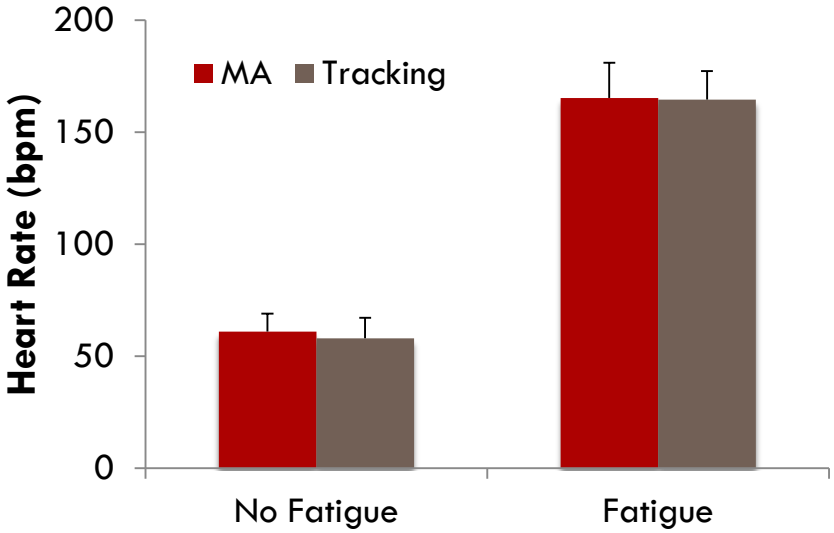
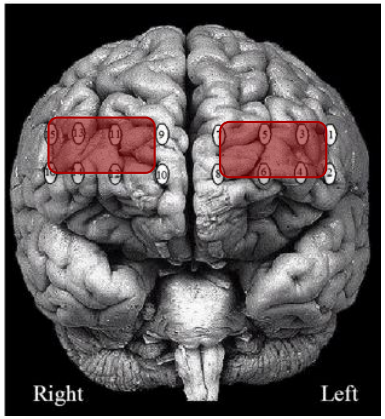
Fatigue Protocol

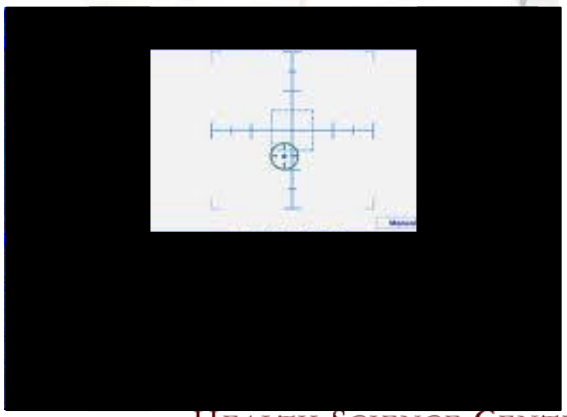


- One hour on a rowing ergometer
  - 3 sets of 20 minute rowing exercises
  - Avg. stroke rate of ~30 strokes/min
- Measures
  - Polar HR monitor (RS800)
    - HR increased significantly from baseline
  - Ratings of Perceived Exertion
    - RPE scores ~7 (Strong)

Neural and Performance Outcomes

- Cerebral oxygenation (Oxy-Hb levels) of the right and left prefrontal cortex
  - Functional Near Infrared Spectroscopy
  - 5 Hz using NIRO 200NX, Hamamatsu Photonics
- Performance:
  - Mental arithmetic: Serial n-subtraction task
    - # correct responses
  - Tracking: Multi-Attribute Task Battery
    - Root Mean Squared (RMS) in range
    - RMS outside range
    - Time inside range



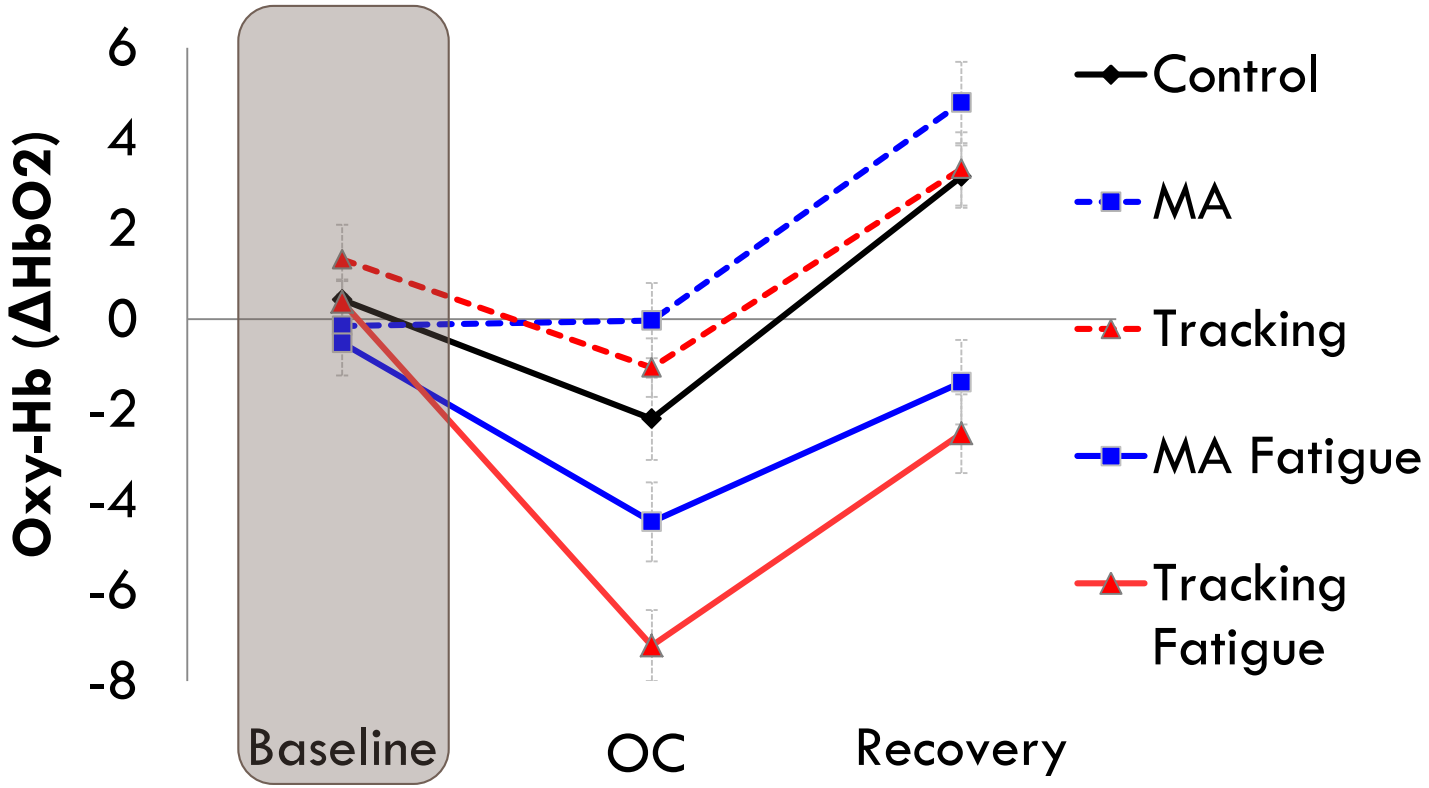


(AFMATB)

Statistical Analyses

- 2 (Fatigue) x 2 (Cognitive Stressor) repeated measures ANOVA
  - Across each phase: Baseline, OC, and Recovery
- Gender: blocking variable
- Bonferroni corrections for post-hoc analyses
- Significance level set at 0.05

Results: Cerebral Oxygenation



Oxy-Hb levels consistent across all conditions during **Baseline** (all $p>0.552$)

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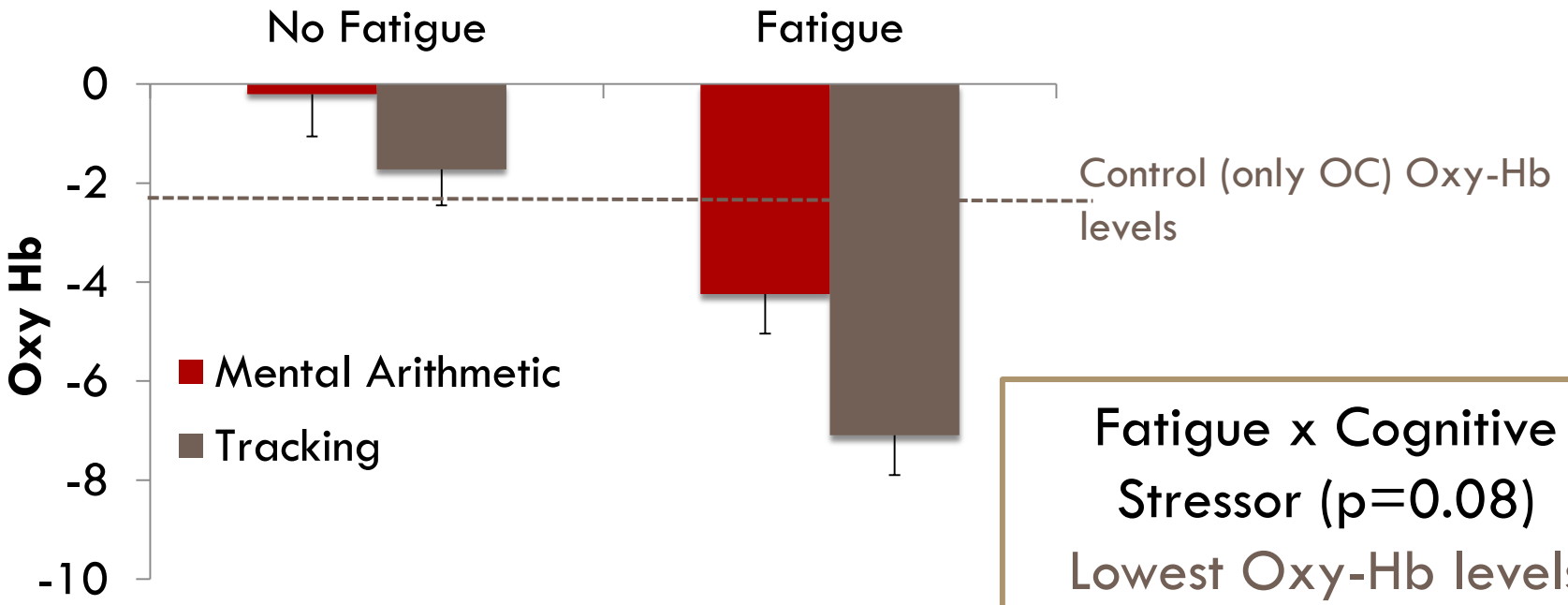
Cerebral Oxygenation: OC

Oxy-Hb levels ↓ during Fatigue ($p<0.0001$) and Tracking ($p=0.015$)



Fatigue x Cognitive Stressor ($p=0.08$)
Lowest Oxy-Hb levels during Tracking Fatigue

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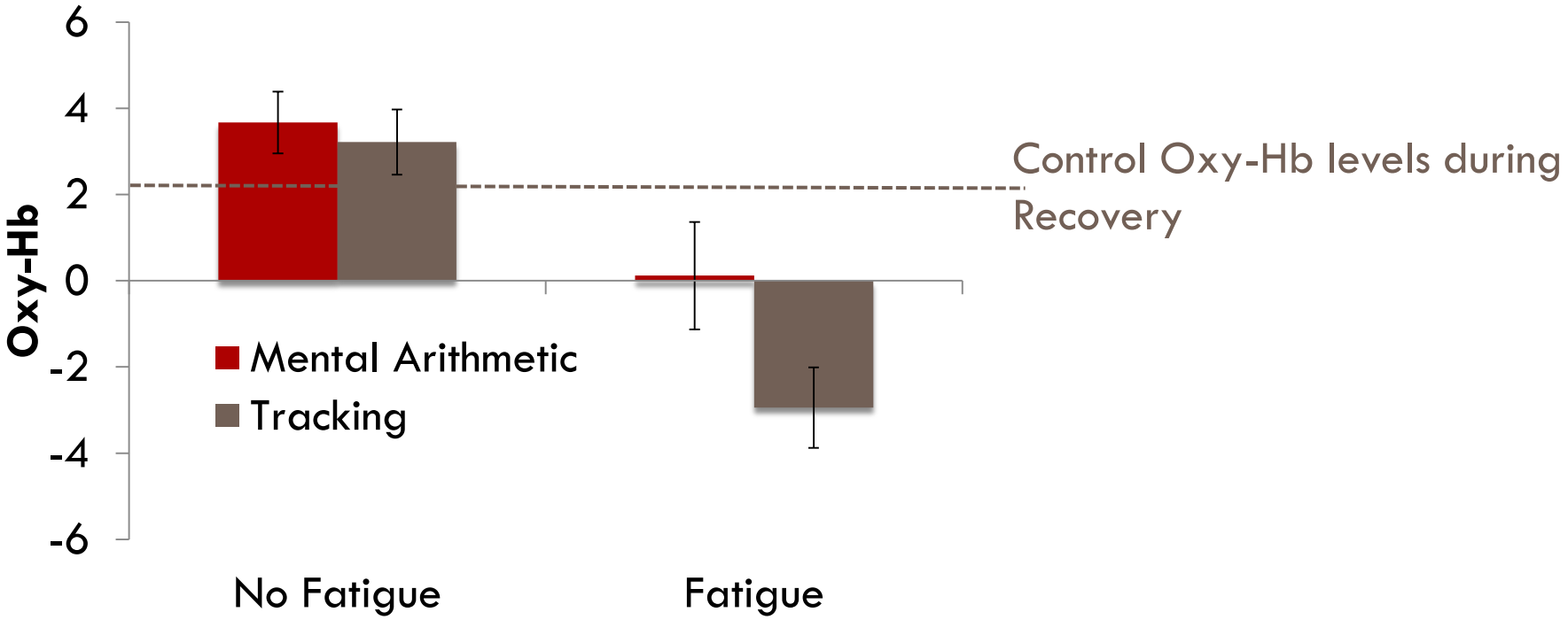
Cerebral Oxygenation: Recovery

Oxy-Hb levels ↓ after Fatigue ($p<0.0001$) and Tracking ($p=0.059$)



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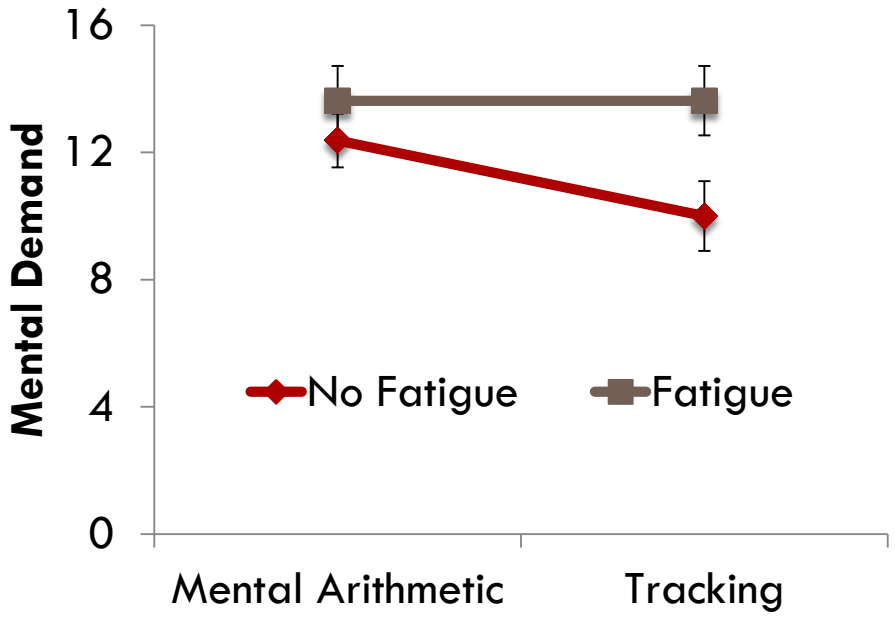
Results: Mental Demand (NASA TLX)

Perceived mental demand ↑ with fatigue (p=0.039) and Tracking (p=0.039)



Fatigue x Cognitive Stressor (p=0.039)

Higher demands during Tracking Fatigue than Mental Arithmetic Fatigue

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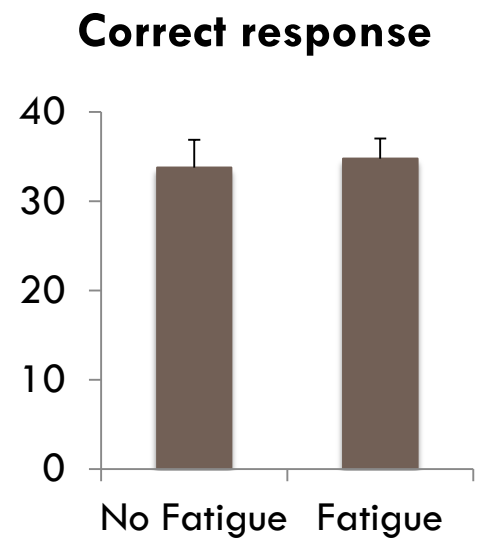
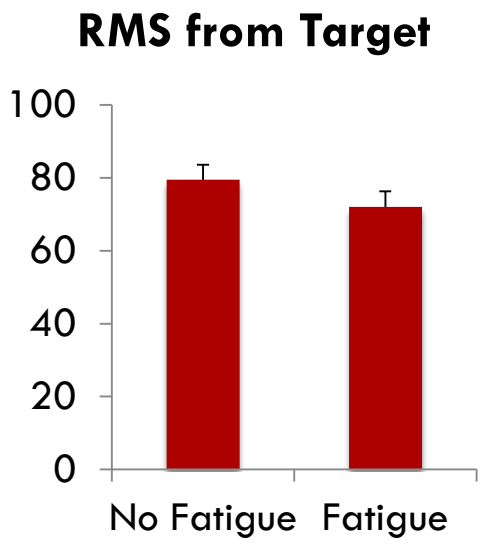
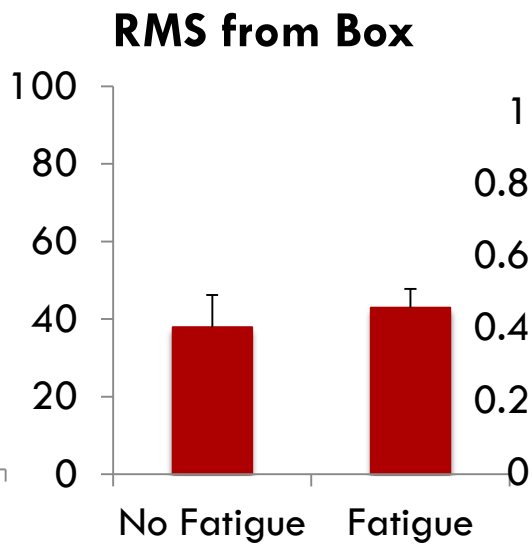
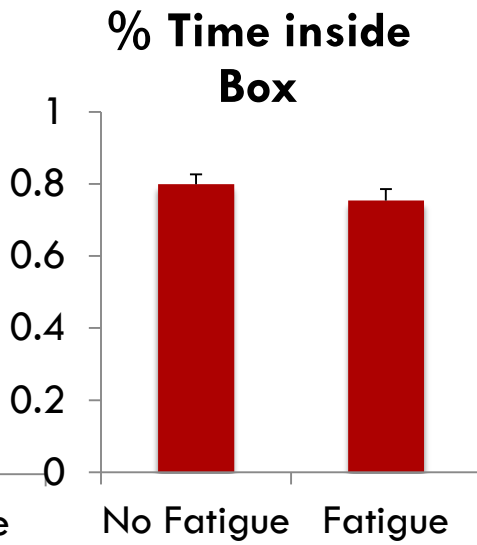
Results: Performance

No difference in arithmetic performance (p=0.509)









No difference in tracking performance (all p>0.11)

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Discussion

- LBNP introduced hemodynamic shift, creating oxygen deficit in the brain
  - Similar to that experienced when entering earth's atmosphere[1]
- Recovery levels higher than Baseline levels
  - Reactive hyperemia: dilation of cerebral blood vessels[2]
- Cognitive stressors are effective countermeasures
  - Increased neuronal activity[3]
  - Attentional tasks more efficient than psychomotor tasks

1 NASA, 2011; 2 Gyton & Hall, 2005, 2 Goswami et al., 2011

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Discussion

- Fatigue mitigates effects of cognitive countermeasures for orthostatic intolerance
  - Decrease cortical efficiency[1]
  - Redistribution of oxygen to fatiguing muscles[2]
  - Performance remained unchanged[3]
- Fatigue x Cognitive Stressor interaction
  - Psychomotor tasks require oxygen supply to cortical and forearm blood vessels[2]
  - Different neural networks for attentional vs psychomotor tasks

1 Lui et al., 2007; 2 Bartels et al., 2011; 3 Evans et al., 2003

Implications for Design

- Findings provide information on performance and neural cost of fatigue during and after orthostatic challenge
  - Operator workload levels to minimize fatigue
  - Non-nominal landing and vehicle egress procedures
    - Interface design: gaze- or voice- compared to motor-controlled, neuro-feedback?
  - Applicable to pilot performance during GLOC forces
    - Adaptive neurophysiological automation systems[1,2]
  - Other occupations (e.g., mining) and populations (post bed-rest patients)

1 McKinley et al., 2005; 2 Albery & Van Patten, 1990

Scope and Future Directions

- Orthostatic challenge limited to avoid syncope
- Limited to monitoring prefrontal cortex
  - Cortical redistribution patterns for cerebral autoregulation due to OC and fatigue effects
- Individual differences in cardiovascular reactivity, motivation, and gaming habits
- Comparing ground-based simulations of microgravity: HUT vs LBNP

Thank You!
Questions?

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Funded by the Michigan Space Grant Consortium

The MSGC is funded in part through a NASA training grant

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